NASA Contractor Report 181881

HIGH-SPEED CIVIL TRANSPORT STUDY

SPECIAL FACTORS

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Boeing Commercial Airplane Group

BOEING COMMERCIAL AIRPLANES
Seattle, Washington

Contract NAS1-18377
September 1990

NASA
National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665-5225

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The "Note" was omitted from Figure 2.3.4-6 on page 19. Attached is a corrected page 19.

Issued December 1990

FOREWORD

In accordance with Statements of Works 7.1 (Emissions), 7.2 (Noise) 7.3 (Fuels) and 7.5.2 (Airport Congestion) in NASA contract NAS1-18377, this documents the work items described.

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SPECIAL FACTORS

1.0 INTRODUCTION

This document records the studies conducted during this phase of the contract that were associated with issues and technologies other than the vehicle itself.

Because these topics are significantly different from each other, each is discussed in a self-contained section.

Included are reports on

- engine emissions as a result of subsonic and supersonic airplane operations
- development of an understanding of the magnitude and nature of the sonic booms that result from supersonic flight and predictions of community noise profiles for supersonic aircraft in takeoff and landing
- fuels considerations for supersonic aircraft such as type, characteristics, availability, cost and support equipment requirements
- and finally the impact a supersonic airplane might have on runway usage in takeoff and landing and on traffic control activities during enroute and approach phases

2.0 EMISSIONS

2.1 INTRODUCTION

During Phase 3 of the contract, engine emissions data were generated that could be used by NASA in their modelling of the potential ozone impact of a projected HSCT fleet.

Following three earlier scenarios developed in Phase 2(two by BCA and one by NASA), a more comprehensive series of cases was developed in Phase 3. These included present-day subsonic fleets and their projections into CY 2000 and 2015, plus several subsonic/supersonic fleet mix scenarios in CY 2015 (Table 2.1-1). Output data were grouped by altitude and latitude.

Assumptions made regarding future airplane and engine developments are identified.

2.2 AIRPLANE FLIGHTS DATA

2.2.1 Subsonic Fleet

The 1987 Official Airline Guide (OAG) was used to establish the operations of the current subsonic fleets (exclusive of the domestic Soviet Union and Eastern Europe fleet operations). The airplane type and flight frequency data was prepared such that it could be processed electronically and combined with the applicable airplane fuel burn and emission information and presented in altitude and latitude format.

The total number of city-pair records processed was slightly more than 29,000, with total weekly departures of 229,794. The calculations produced values of fuel burned per week at 26,000 and 37,000 feet (altitudes representing cruise altitudes for stage lengths less than and greater than 400 miles) in each 10^{o} band of latitude for each of the 32 jet airplane types.

This set of data formed the basis for estimation of the fuel burned and emissions produced by the subsonic jet transport fleet in the years 2000 and 2015. Given the total ASM's produced by each type in the fleet in 1987, and a forecast of ASM's for each of the types in 2000 and 2015, the number of departures for each type in 2000 and 2015 were calculated (average stage length was assumed to remain constant).

New jet transport types introduced into the fleet in 2000 and 2015 were assumed to take the place of specific types now in the fleet, and so have average stage length and service patterns similar to the airplanes being replaced. Thus (for example) the A320 is assumed to have a service pattern similar to the 727-200, and the proposed "LR-440" is similar to the 747-200. With the ASM forecasts for each of these new and proposed models, and using the average stage length and service patterns of the types replaced, the number of departures for each new and proposed type were calculated. Tables 2.2.1-1 and 2.2.1-2 show the ASM's and departures calculated for each airplane type for the years 2000 and 2015, using the 1987 ASM level as a base (where the 1987 ASM column contains an airplane type, that types average trip distance and service pattern is assumed in calculating the number of departures and fuel burned distribution by latitude).

2.2.2 Supersonic Fleet

The introduction of the HSCT into the projected fleet required that the long range subsonic fleet be reduced to keep the same total fleet ASM capacity. Table 2.2.2-1 shows the ASM forecast for the long range airplane types through 2015 with and without the HSCT.

Table 2.2.2-1
ASM FORECAST (MILLIONS)
OPEN

	1988	1990	1995	2000	2005	2015	2015
LONG RANGE					NO HSCT		w/HSCT
LR-220	0	1092	6125	10388	13518	82075	50472
LR-270	420	9481	55961	94622	127779	237105	145807
LR-320	328	4231	17780	38219	65811	185829	114275
LR-370	0	2079	12431	25319	39020	110506	67956
LR-440	1033	15920	36154	92295	140417	229714	141262
LR-520	0	4714	54477	155674	257790	786371	483578
LR-620	0	0	16950	87438	197275	344571	211893
LR-800	0	1090	3270	18728	86122	137828	84757
HSCT	0	0	0	0	0	0	814000
	1781	38607	203148	522683	927732	2114000	2114000

2.3 FUEL BURN AND EMISSIONS DATA

2.3.1 Subsonic Fleet

Table 2.3.1-1 lists the relevant fuel flows and emission data for each of the aircraft types that appear in the subsonic fleets calculations.

For the later years (CY 2000 and 2015), retirements and replacements occurring in the subsonic fleets have been assumed as indicated in Table 2.3.1-2 and the impact on fuel flow and emissions is as assumed in Table 2.3.1-3.

The emissions data for the year 2000 was estimated as an average of P&W and G.E. data with a 20% emissions increase for a 100^{O}F increase in combustor inlet temperature by year 2000. It was assumed that emissions increase from year 2000 to 2015 will only come from fleet growth and that any increase in combustor temperature will be offset by lower NOx technology combustors, so the year 2000 emission indices were retained.

2.3.2 Supersonic Fleet

Table 2.3.2-1 lists the relevant emissions data for each of the supersonic cases and engine assumptions.

The fuel burned in each 10^{o} latitude band for each HSCT evaluation was calculated by running the OVERLAND computer model and the waypoint (sonic boom avoidance) path routings devised for the HSCT scheduling model.

2.3.3 Data Format

The calculation of emissions in molecules/second, required as an input for one of the atmospheric models being used by NASA, was done using the transformation shown below in steps:

a) (lbs./day) x (453.6 grams/lb.) = grams/day
b) (grams/day) / (86400 seconds/day) = grams/second
c) (grams/second) / (molecular weight of emission) = moles/sec
d) (moles/sec) x (Avogadro's Number) = molecules/sec.

2.3.4 Data Tables

The following list of tables contain the data that was supplied for NASA to input to their ozone modelling.

Fig. 2.3.4-1	Case B4	YR 1987	26000 Ft. Fuel & Emissions lb/day
			37000 Ft. Fuel & Emissions lb/day
Fig. 2.3.4.2	Case B4	YR 1987	55000 Ft. Fuel & Emissions lb/day
Fig. 2.3.4.3	Case B5	YR 2000	26000 Ft. Fuel & Emissions lb/day
			37000 Ft. Fuel & Emissions lb/day
Fig. 2.3.4-4	Case B6	YR 2015	26000 Ft. Fuel & Emissions lb/day
			37000 Ft. Fuel & Emissions lb/day
Fig. 2.3.4-5	Case B7	YR 2015	26000 Ft. Fuel & Emissions lb/day
			37000 Ft. Fuel & Emissions lb/day
Fig. 2.3.4-6	Case B7	YR 2015	60000 Ft. Fuel & Emissions lb/day
Fig. 2.3.4-7	Case B8	YR 2015	26000 Ft. Fuel & Emissions lb/day
			37000 Ft. Fuel & Emissions lb/day
Fig. 2.3.4-8	Case B8	YR 2015	58500 Ft. Fuel & Emissions lb/day
Fig. 2.3.4-9	Case B9	YR 2015	26000 Ft. Fuel & Emissions lb/day
			37000 Ft. Fuel & Emissions lb/day
Fig. 2.3.4-10	Case B9	YR 2015	56700 Ft. Fuel & Emissions lb/day
Fig. 2.3.4-11	Case B10	YR 2015	26000 Ft. Fuel & Emissions lb/day
			37000 Ft. Fuel & Emissions lb/day
Fig. 2.3.4-12	Case B10	YR 2015	46000 Ft. Fuel & Emissions lb/day
Fig. 2.3.4-13	Case B10	YR 2015	60000 Ft. Fuel & Emissions lb/day
Fig. 2.3.4-14	Case B4	YR 1987	26000 Ft Emissions Molecules/sec
			37000 Ft Emissions Molecules/sec
Fig. 2.3.4-15	Case B4	YR 1987	55000 Ft Emissions Molecules/sec
Fig. 2.3.4-16	Case B5	YR 2000	26000 Ft Emissions Molecules/sec
			37000 Ft Emissions Molecules/sec
Fig. 2.3.4-17	Case B6	YR 2015	26000 Ft Emissions Molecules/sec
			37000 Ft Emissions Molecules/sec
Fig. 2.3.4-18	Case B7	YR 2015	26000 Ft Emissions Molecules/sec
			37000 Ft Emissions Molecules/sec
Fig. 2.3.4-19	Case B7	YR 2015	60000 Ft Emissions Molecules/sec
Fig. 2.3.4-20	Case B8	YR 2015	26000 Ft Emissions Molecules/sec
			37000 Ft Emissions Molecules/sec
Fig. 2.3.4-21	Case B8	YR 2015	58500 Ft Emissions Molecules/sec
Fig. 2.3.4-22	Case B9	YR 2015	26000 Ft Emissions Molecules/sec
			37000 Ft Emissions Molecules/sec
Fig. 2.3.4-23	Case B9	YR 2015	56700 Ft Emissions Molecules/sec
Fig. 2.3.4-24	Case B10	YR 2015	26000 Ft Emissions Molecules/sec
			37000 Ft Emissions Molecules/sec
Fig. 2.3.4-25	Case B10	YR 2015	46000 Ft Emissions Molecules/sec
Fig. 2.3.4-26	Case B10	YR 2015	60000 Ft Emissions Molecules/sec

OZONE EVALUATIONS

EVAL	DATE	FLEET TYPE	NOx TECHNOLOGY	COMMENTS
B4-SUB87	1987	CURRENT SUBSONIC	ESTIMATED NOx FOR CURRENT FLEET	ESTIMATED NOx FOR CURRENT FLEET.
B5-SUB2000	2000	EST YEAR 2000 SUBSONIC	ESTIMATED NOx FOR Y2000 FLEET	REFLECTS RETIREMENTS, REPLACEMENTS & GROWTH.
B6-SUB2015	2015	EST YEAR 2015 SUBSONIC ONLY	AVG EST NOx FOR Y2015 FLEET	REFLECTS RETIREMENTS, REPLACEMENTS & GROWTH. ASSUMES IMPLEMENTATION OF LOW NOx COMBUSTOR TECHNOLOGY NO SST.
B7-OW2.4/OL0.9	2015	EST YEAR 2015 SUB/SUPERSONIC MIX	SUPERSONIC NOx FROM EMISSION TECHNOLOGY SENSITIVITY(TASK 8) FOR M2.4 A/P, ALT = 60K. AVG SUBSONIC NOx FROM B6.	SUBSONIC FLEET SIZE TO COMPLEMENT SUPERSONIC FLEET
B8-OW2.4/OL0.9	2015	EST YEAR 2015 SUB/SUPERSONIC MIX	SUPERSONIC NOx FROM EMISSION TECHNOLOGY SENSITIVITY(TASK 8) FOR M2.4 A/P, ALT = 58.5K. AVG SUBSONIC NOx FROM B6.	SAME AS EVAL. B7. SECOND DATA SET.
B9-OW2.1/OL0.9	2015	EST YEAR 2015 SUB/SUPERSONIC MIX	SUPERSONIC NOx FROM EITHER B7 OR B8, FOR M2.1 A/P, ALT = 56.7K. AVG SUBSONIC NOx FROM B6.	MODIFIED SUB/SUPERSONIC FLEET MIX TO REFLECT M2.1 UTILIZATION
B10-OW2.4/OL1.5	2015	EST YEAR 2015 SUB/SUPERSONIC MIX	NOx FOR M1.5 OVERLAND(46K) & SUPERSONIC NOx FROM EITHER B7 OR B8, M2.4, ALT = 60K. AVG SUBSONIC NOx FROM B6.	MODIFIED SUB/SUPERSONIC FLEET MIX TO REFLECT M1.5 OVERLAND. MODIFIED FROM EITHER B7 OR B8.

OW = OVERWATER
OL = OVERLAND

Table 2.1-1

ASM ADJUSTER FOR FORECASTING 09-Aug-88
YEAR 2000

AIRPLANE	(ASMFORC) 1987 ASMS/WK	1987 AMS/YR (MILLIONS)	YR 2000 ASM/YR (MILLIONS)	1987 AVG TRIP	1987 WEEKLY DEP	1987 SEATS	2000 WEEKLY DEP	2000/1987 DEP FACT
B707	254,254,800	13,221	2,163	1,057	1,595	151	261	0.164
B720	11,941,500	621	0	520	173	133	0	0.000
727-100	776,456,960	40,376	383	532	12,052	121	114	0.009
727-200	3,975,129,600	206,707	136,613	643	40,992	151	27,092	0.661
737-200	2,159,302,660	112,284	90,366	409	46,510	113	37,431	0.805
737-300	676,667,392	35,187	98,425	549	9,199	134	25,732	2.797
737-400	737-200	1,027	11,184	409		146	3,602	0.077
737-500	737-200	0	3,277	409		108	1,427	0.031
747-100/200	7,813,231,422	406,288	214,259	2,587	7,759	389	4,092	0.527
747-300	882,471,424	45,889	59,659	2,559	891	387	1,158	1.300
747-SP	496,714,752	25,829	18,705	3,344	469	317	340	0.724
747-SR	88,891,248	4,622	9,584	531	364	460	755	2.073
747-400	747-300	3,834	107,277	2,850		412	1,757	1.972
757-200	616,772,352	32,072	56,340	777	4,165	190	7,317	1.757
767-200	1,151,153,660	59,860	54,987	1,233	4,558	205	4,187	0.919
767-300	64,668,544	3,363	31,650	809	297	269	2,795	9.412
A300	1,336,222,208	69,484	71,739	749	7,027	254	7,255	1.032
A300-600	35,638,080	1,853	22,759	1,748	80	255	982	12.281
A310	405,211,392	21,071	40,999	864	2,196	213	4,273	1.946
A320	727-200	1,178	54,582	643		150	10,883	0.265
A330	DC-10-10	0	1,682	1,800		267	67	0.011
A340	747-200	0	27,080	2,500		245	850	0.110
BAC-111	116,157,040	6,040	134	337	4,058	85	90	0.022
BAE-146	95,763,120	4,980	5,341	306	4,122	76	4,421	1.073
CARAVELLE	21,675,296	1,127	0	328	546	121	0	0.000
CONCORDE	18,168,384	945	0	3,244	56	100	0	0.000
DC-8-50	33,130,624	1,723		792	258	162	0	0.000
DC-8-60	321,819,904	16,735	360	1,095	1,584	186	34	0.022
DC-9-30	1,517,597,950	78,915	17,040	382	38,373	103	8,286	0.216
DC-10-10	2,629,951,740	136,757	34,020	1,723	5,976	255	1,487	0.249
DC-10-30	909,364,480	47,287	79,929	3,049	1,137	262	1,922	1.690
MD-11	DC-10-30	0	20,913	3,049		274	481	0.423
F-28	179,920,336	9,356	6,296	268	8,991	75	6,050	0.673
F-100	DC-9-30	2,267	8,525	300		103	5,306	0.138
MD-80	1,253,792,770	65,197	109,587	598	14,181	148	23,836	1.681
MD-87	DC-9-30	1,504	5,725	382		118	2,442	0.064
IL-62	223,471,680	11,621		1,898	741	159	0	0.000
IL-86	159,163,488	8,277		1,262	399	316	0	0.000
L-1011	2,731,097,340	142,017	56,598	1,733	5,645	279	2,250	0.399
TRIDENT	22,532,048	1,172	0	619	364	100	0	0.000
TU-134	86,677,952	4,507		551	2,090	75	0	0.000
TU-154	342,125,056	17,791	2,594	890	2,513	153	366	0.146
YAK-40	4,764,262	248	57	368	433	30	100	0.230

Table 2.2.1-1

ASM ADJUSTER FOR FORECASTING 09-Aug-88
YEAR 2000

AIRPLANE	(ASMFORC) 1987 ASMS/WK	1987 AMS/YR (MILLIONS)	YR 2000 ASM/YR (MILLIONS)	1987 AVG TRIP	1987 WEEKLY DEP	1987 SEATS	2000 WEEKLY DEP	2000/1987 DEP FACT
LR-220	767-200	0	10,388	1,233		220	736	0.162
LR-270	767-200	420	94,622	1,233		270	5,466	1.199
LR-320	DC-10-30	328	38,219	3,049		320	753	0.663
LR-370	DC-10-30	0	25,319	3,049		370	432	0.380
LR-440	747-200	1,033	92,295	2,587		440	1,559	0.201
LR-520	747-200	0	155,674	2,587		520	2,225	0.287
LR-620	747-300	0	87,438	2,559		620	1,060	1.189
LR-800	747-SR	0	18,728	531		800	848	2.329
MR-110	727-100	0	7,583	532		110	2,492	0.207
MR-130	737-300	303	31,831	549		130	8,577	0.932
MR-150	727-200	1,092	115,857	643		150	23,100	0.564
MR-180	757-200	1,754	165,540	777		180	22,762	5.465
MR-220	767-200	0	87,080	1,233		220	6,173	1.354
MR-270	767-200	2,747	87,556	1,233		270	5,058	1.110
MR-320	DC-10-10	4,104	151,147	1,723		320	5,272	0.882
MR-370	DC-10-10	0	41,640	1,723		370	1,256	0.210
MR-440	DC-10-10	0	5,432	1,723		440	138	0.023
MR-520	747-SR	0	13,347	531		520	930	2.554
MR-620	747-SR	0	3,966	531		620	232	0.636
SR-80	BAE-146	0	1,706	306		80	1,340	0.325
SR-110	DC-9-30	0	13,448	382		110	6,155	0.160
SR-130	DC-9-30	0	23,275	382		130	9,013	0.235
SR-150	DC-9-30	0	2,837	382		150	952	0.025
TOTAL	31,411,901,464	1,633,419	2,735,760		229,794		305,970	

Table 2.2.1-1 con't

ASM ADJUSTER FOR FORECASTING 09-Aug-88
YEAR 2015

AIRPLANE	1987 ASMS/WK	1987 AMS/YR (MILLIONS)	YR 2015 ASM/YR (MILLIONS)	1987 AVG TRIP	1987 WEEKLY DEP	1987 SEATS	2015 WEEKLY DEP	2015/1987 DEP FACT
B707	254,254,800	13,221	0	1,057	1,595	151	0	0.000
B720	11,941,500	621	0	520	173	133	0	0.000
727-100	776,456,960	40,376	0	532	12,052	121	0	0.000
727-200	3,975,129,600	206,707	0	643	40,992	151	0	0.000
737-200	2,159,302,660	112,284	0	409	46,510	113	0	0.000
737-300	676,667,392	35,187	36,764	549	9,199	134	9,611	1.045
737-400	737-200	1,027	11,268	409		146	3,629	0.078
737-500	737-200	0	3,277	409		108	1,427	0.031
747-100/200	7,813,231,422	406,288	0	2,587	7,759	389	0	0.000
747-300	882,471,424	45,889	2,248	2,559	891	387	44	0.049
747-SP	496,714,752	25,829	0	3,344	469	317	0	0.000
747-SR	88,891,248	4,622	732	531	364	460	58	0.158
747-400	747-300	3,834	107,264	2,850		412	1,757	1.972
757-200	616,772,352	32,072	10,922	777	4,165	190	1,418	0.341
767-200	1,151,153,660	59,860	1,832	1,233	4,558	205	139	0.031
767-300	64,668,544	3,363	18,929	809	297	269	1,672	5.629
A300	1,336,222,208	69,484	0	749	7,027	254	0	0.000
A300-600	35,638,080	1,853	7,767	1,748	80	255	335	4.191
A310	405,211,392	21,071	6,512	864	2,196	213	679	0.309
A320	727-200	1,178	55,488	643		150	11,064	0.270
A330	DC-10-10	0	1,695	1,800		267	68	0.011
A340	747-200	0	27,322	2,500		245	858	0.111
BAC-111	116,157,040	6,040	0	337	4,058	85	0	0.000
BAE-146	95,763,120	4,980	591	306	4,122	76	489	0.119
CARAVELLE	21,675,296	1,127	0	328	546	121	0	0.000
CONCORDE	18,168,384	945	0	3,244	56	100	0	0.000
DC-8-50	33,130,624	1,723		792	258	162	0	0.000
DC-8-60	321,819,904	16,735	0	1,095	1,584	186	0	0.000
DC-9-30	1,517,597,950	78,915	0	382	38,373	103	0	0.000
DC-10-10	2,629,951,740	136,757	0	1,723	5,976	255	0	0.000
DC-10-30	909,364,480	47,287	0	3,049	1,137	262	0	0.000
MD-11	DC-10-30	0	20,913	3,049		274	481	0.423
F-28	179,920,336	9,356	0	268	8,991	75	0	0.000
F-100	DC-9-30	2,267	6,330	300		103	3,940	0.103
MD-80	1,253,792,770	65,197	30,474	598	14,181	148	6,628	0.467
MD-87	DC-9-30	1,504	5,725	382		118	2,442	0.064
IL-62	223,471,680	11,621		1,898	741	159	0	0.000
IL-86	159,163,488	8,277		1,262	399	316	0	0.000
L-1011	2,731,097,340	142,017	0	1,733	5,645	279	0	0.000
TRIDENT	22,532,048	1,172	0	619	364	100	0	0.000
TU-134	86,677,952	4,507		551	2,090	75	0	0.000
TU-154	342,125,056	17,791	0	890	2,513	153	0	0.000
YAK-40	4,764,262	248	0	368	433	30	0	0.000

Table 2.2.1-2

ASM ADJUSTER FOR FORECASTING 09-Aug-88
YEAR 2015

AIRPLANE	1987 ASMS/WK	1987 AMS/YR (MILLIONS)	YR 2015 ASM/YR (MILLIONS)	1987 AVG TRIP	1987 WEEKLY DEP	1987 SEATS	2015 WEEKLY DEP	2015/1987 DEP FACT
LR-220	767-200	0	82,075	1,233		220	5,819	1.277
LR-270	767-200	420	237,105	1,233		270	13,697	3.005
LR-320	DC-10-30	328	185,829	3,049		320	3,663	3.221
LR-370	DC-10-30	0	110,506	3,049		370	1,884	1.657
LR-440	747-200	1,033	229,714	2,587		440	3,881	0.500
LR-520	747-200	0	786,371	2,587		520	11,242	1.449
LR-620	747-300	0	344,571	2,559		620	4,177	4.687
LR-800	747-SR	0	137,828	531		800	6,239	17.141
MR-110	727-100	0	8,090	532		110	2,659	0.221
MR-130	737-300	303	152,011	549		130	40,960	4.453
MR-150	727-200	1,092	463,370	643		150	92,389	2.254
MR-180	757-200	1,754	339,795	777		180	46,722	11.218
MR-220	767-200	0	337,828	1,233		220	23,950	5.255
MR-270	767-200	2,747	292,727	1,233		270	16,910	3.710
MR-320	DC-10-10	4,104	432,811	1,723		320	15,096	2.526
MR-370	DC-10-10	0	188,775	1,723		370	5,694	0.953
MR-440	DC-10-10	0	16,181	1,723		440	410	0.069
MR-520	747-SR	0	47,810	531		520	3,330	9.148
MR-620	747-SR	0	13,484	531		620	788	2.164
SR-80	BAE-146	0	10,196	306		80	8,010	1.943
SR-110	DC-9-30	0	152,200	382		110	69,655	1.815
SR-130	DC-9-30	0	51,239	382		130	19,842	0.517
SR-150	DC-9-30	0	13,484	382		150	4,525	0.118
TOTAL	31,411,901,464	1,633,419	4,990,053		229,794		448,279	

Table 2.2.1-2 con't

CURRENT SUBSONIC FLEET(B4-SUB87)

MISSION DATA FOR DEVELOPING EMISSION INFORMATION 06/07/88

MODEL	APPLY TO 26000 FT ALT.	#/HR		APPLY TO 37000 FT ALT.	#/HR		EMISSIONS INDEX (EI) - G/KG					
	KTAS	100% P/L	50% P/L	KTAS	100% P/L	50% P/L	CO	HC	NOx	SO2	CO2	H2O
707	259	8,917	8,204	375	9,313	8,568	13.8	4.60	6.3	1.1	3,160	1,233
720B	259	7,715	7,098	336	7,910	7,277	13.8	4.60	6.3	1.1	3,160	1,233
727-100	262	6,759	6,218	337	6,924	6,370	7.5	1.00	7.6	1.1	3,160	1,233
727-200	265	8,145	7,493	349	8,369	7,699	7.5	1.00	7.6	1.1	3,160	1,233
737-200	252	4,616	4,247	302	4,692	4,316	6.6	1.00	7.9	1.1	3,160	1,233
737-300	256	4,405	4,053	334	4,526	4,164	1.9	0.10	7.4	1.1	3,160	1,233
747-200	280	18,970	17,452	428	21,480	19,761	1.1	0.17	18.8	1.1	3,160	1,233
747-300	275	18,621	17,132	433	21,099	19,411	1.1	0.17	18.8	1.1	3,160	1,233
747-SP	288	16,175	14,881	432	18,048	16,604	1.1	0.17	18.8	1.1	3,160	1,233
747-SR	274	22,804	20,980	309	23,090	21,243	1.1	0.17	18.8	1.1	3,160	1,233
757-200	271	6,169	5,675	357	6,352	5,844	1.5	0.12	14.0	1.1	3,160	1,233
767-200	278	7,892	7,261	388	8,240	7,581	1.1	0.16	19.4	1.1	3,160	1,233
767-300	271	7,983	7,345	358	8,224	7,566	1.1	0.16	19.4	1.1	3,160	1,233
A300B3	272	11,365	10,456	345	11,641	10,710	0.2	0.24	14.0	1.1	3,160	1,233
A300B4	272	11,001	10,121	356	11,317	10,412	0.2	0.24	14.0	1.1	3,160	1,233
A300-600	281	9,198	8,462	411	9,766	8,985	0.2	0.24	14.0	1.1	3,160	1,233
A310	272	8,159	7,507	375	8,466	7,789	0.2	0.24	14.0	1.1	3,160	1,233
BAC-111	246	4,684	4,309	290	4,752	4,372	7.5	1.00	7.6	1.1	3,160	1,233
BAE-146	243	4,204	3,867	261	4,230	3,892	7.5	1.00	7.6	1.1	3,160	1,233
CARAVELLE	331	4,428	4,074	351	4,457	4,100	7.5	1.00	7.6	1.1	3,160	1,233
CONCORDE	444	32,897	30,265	874	38,462	35,385	3.5	0.20	19.0	1.1	3,160	1,233
DC-8-50	281	9,187	8,452	334	9,373	8,623	13.8	4.60	6.3	1.1	3,160	1,233
DC-8-60	273	10,459	9,622	366	10,815	9,949	1.9	0.10	7.4	1.1	3,160	1,233
DC-9-30	255	4,871	4,482	306	4,951	4,555	7.5	1.00	7.6	1.1	3,160	1,233
DC-10-10	271	12,817	11,792	412	13,601	12,513	1.1	0.16	19.4	1.1	3,160	1,233
DC-10-30	274	13,033	11,990	433	15,102	13,894	1.2	0.20	16.3	1.1	3,160	1,233
F-28	224	3,876	3,566	254	3,932	3,618	7.5	1.00	7.6	1.1	3,160	1,233
MD-80	261	5,281	4,859	334	5,412	4,979	3.6	1.50	12.6	1.1	3,160	1,233
ILYUSHIN	262	8,925	8,211	398	9,471	8,713	13.8	4.60	6.3	1.1	3,160	1,233
ILYUSHIN	284	12,863	11,834	382	13,328	12,262	1.1	0.16	19.4	1.1	3,160	1,233
L-1011	288	13,710	12,613	434	14,590	13,423	1.1	0.16	19.4	1.1	3,160	1,233
TRIDENT	278	5,739	5,280	344	5,865	5,396	7.5	1.00	7.6	1.1	3,160	1,233
TUPOLEV	245	4,361	4,012	280	4,434	4,079	7.5	1.00	7.6	1.1	3,160	1,233
TUPOLEV	279	8,287	7,624	358	8,514	7,833	7.5	1.00	7.6	1.1	3,160	1,233
YAKOVLEV	252	2,459	2,262	290	2,494	2,295	7.5	1.00	7.6	1.1	3,160	1,233

Table 2.3.1-2

MODEL	SEATS	GENERIC
F-28	69	SR-80
*BAE-146	80	SR-80
TRIDENT	85	SR-80
BAC-111	85	SR-80
CARAVELLE	85	SR-80
F-100	102	SR-110
737-200	110	SR-110
*DC-9-30	110	SR-110
DC-9-50	121	SR-130
*DC-9-30	130	SR-130
*DC-9-30	150	SR-150
737-500	108	MR-108
*727-100	110	MR-110
MD-87	121	MR-110
*737-300	130	MR-130
720B	152	MR-130
MD-80	146	MR-150
737-400	146	MR-150
TU-134		
TU-154	150	MR-150
YAK-40		
IL-62	150	MR-150
IL-86		
*727-200	150	MR-150
A320	152	MR-150
*757-200	180	MR-180
*767-200	220	MR-220
A310	238	MR-220
*767-200	270	MR-270
A300-B3/B4	274	MR-270
767-300	281	MR-270
A300-600	290	MR-320
L-1011	316	MR-320
*DC-10-10	320	MR-320
A330	359	MR-320
*DC-10-10	370	MR-370
*DC-10-10	440	MR-440
*747-SR	520	MR-520
*747-SR	620	MR-620
707	180	LR-180
DC-8-50	187	LR-180
DC-8-60	200	LR-200
*767-200	220	LR-220
*767-200	270	LR-270
*DC-10-30	320	LR-320
*DC-10-30	370	LR-370
747-SP	371	LR-370
*747-200	440	LR-440
*747-200	520	LR-520
747-300	562	LR-520
*747-300	620	LR-620
*747-SR	800	LR-800

*Indicates updated airplane to represent generic fleet model.

GENERIC SUBSONIC FLEETS

YEAR 2000 B5-SUB2000

YEAR 2015 B6-SUB2015

MODEL	REPRESENTED BY	PASSENGER LOAD 65% AT 26,000' ALT KTAS	PASSENGER LOAD 65% AT 26,000' ALT WF(LB/HR)	PASSENGER LOAD 65% AT 37,000' ALT KTAS	PASSENGER LOAD 65% AT 37,000' ALT WF(LB/HR)	EMISSIONS EI (G/KG) CO	EMISSIONS EI (G/KG) HC	EMISSIONS EI (G/KG) NOX
SR-80	BAE-146	243	3,728	261	3,751	1	0.2	14.4
SR-110	DC-9-30	255	4,137	306	4,205	1	0.2	14.4
SR-130	DC-9-30	255	4,264	306	4,334	1	0.2	14.4
SR-150	DC-9-30	255	4,688	307	4,764	1	0.2	14.4
MR-110	727-100	262	4,594	337	4,708	1	0.2	14.4
MR-130	737-300	256	3,961	334	4,069	1	0.2	14.4
MR-150	727-200	265	4,059	349	4,171	1	0.2	14.4
MR-180	757-200	271	5,435	357	5,597	1	0.2	14.4
MR-220	767-200	278	7,010	388	7,319	1	0.2	14.4
MR-270	767-200	278	7,114	388	7,329	1	0.2	14.4
MR-320	DC-10-10	271	8,385	412	8,903	1	0.2	14.4
MR-370	DC-10-10	271	8,613	412	9,145	1	0.2	14.4
MR-440	DC-10-10	271	12,138	412	12,879	1	0.2	14.4
MR-520	747-SR	274	20,451	309	20,707	1	0.2	14.4
MR-620	747-SR	274	21,080	309	21,344	1	0.2	14.4
LR-220	767-200	278	7,010	388	7,319	1	0.2	14.4
LR-270	767-200	278	7,252	388	7,572	1	0.2	14.4
LR-320	DC-10-30	274	11,813	433	13,688	1	0.2	14.4
LR-370	DC-10-30	274	12,124	433	14,049	1	0.2	14.4
LR-440	747-200	280	16,593	428	18,789	1	0.2	14.4
LR-520	747-200	280	17,012	428	19,263	1	0.2	14.4
LR-620	747-300	275	16,976	433	19,234	1	0.2	14.4
LR-800	747-SR	274	21,836	309	22,110	1	0.2	14.4

SUPERSONIC ENGINES EMISSIONS INDEX FOR YEAR 2015 SUB/SUPERSONIC FLEET MIX

Mach2.4 P&W Engine for B7-OW2.4/OL0.9 — Low Emis.

MACH No.	EMISSIONS INDEX g/kg					
	CO	HC	NOx	SO_2	CO_2	H_2O
0.9	20.0	2.0	1.5	1.0	3160	1233
2.4	3.0	0.3	5.0	1.0	3160	1233

TRACE METALS 10^{-9} g/kg

Mach2.4 GE Engine for B8-OW2.4/OL0.9 — Low Emis.

MACH No.	EMISSIONS INDEX g/kg					
	CO	HC	NOx	SO_2	CO_2	H_2O
0.9	107.	4.8	3.0	1.2	3153	1242
2.4	7.0	0.1	9.0	1.2	3153	1242

TRACE METALS 10^{-9} g/kg

MACH2.1 P&W Engine for B9-OW2.1/OL0.9

MACH No.	EMISSIONS INDEX g/kg					
	CO	HC	NOx	SO_2	CO_2	H_2O
0.9	20.	2.0	1.5	1.0	3160	1233
2.1	3.	0.3	5.0	1.0	3160	1233

TRACE METALS 10^{-9} g/kg

MACH2.4 P&W Engine for B10-OW2.4/OL1.5(Low boom/M1.5 overland)

MACH No.	EMISSIONS INDEX g/kg					
	CO	HC	NOx	SO_2	CO_2	H_2O
1.5	3.0	0.3	2.9	1.0	3160	1233
2.4	3.0	0.3	5.0	1.0	3160	1233

TRACE METALS 10^{-9} g/kg

Table 2.3.2-1

CASE B4-SUB87
CURRENT SUBSONIC FLEET (YEAR 1987)

26,000 FT ALTITUDE	TOTAL FUEL LBS/DAY	TOTAL CO LBS/DAY	TOTAL HC LBS/DAY	TOTAL NO LBS/DAY	TOTAL NO2 LBS/DAY	TOTAL SO2 LBS/DAY	TOTAL CO2 LBS/DAY	TOTAL H2O LBS/DAY
80 - 90S	0	0	0	0	0	0	0	0
70 - 80S	0	0	0	0	0	0	0	0
60 - 70S	0	0	0	0	0	0	0	0
50 - 60S	21,821	141	25	164	29	24	68,954	26,905
40 - 50S	343,524	2,319	339	2,349	415	378	1,085,537	423,566
30 - 40S	1,099,366	6,970	1,002	7,905	1,395	1,209	3,473,998	1,355,519
20 - 30S	1,494,951	7,571	1,225	13,822	2,439	1,644	4,724,046	1,843,275
10 - 20S	719,197	5,630	1,055	4,731	835	791	2,272,662	886,770
0 - 10S	1,425,900	9,995	1,702	10,227	1,805	1,568	4,505,844	1,758,135
0 - 10N	1,799,560	10,730	1,664	14,213	2,508	1,980	5,686,674	2,218,883
10 - 20N	2,699,330	14,791	2,238	23,073	4,072	2,969	8,529,884	3,328,274
20 - 30N	5,393,155	31,467	4,736	42,718	7,538	5,932	17,042,369	6,649,760
30 - 40N	25,151,782	148,584	23,418	198,259	34,987	27,667	79,479,631	31,012,147
40 - 50N	20,244,674	118,745	17,657	160,923	28,398	22,269	63,973,170	24,961,683
50 - 60N	7,151,962	41,834	5,899	58,222	10,274	7,867	22,600,201	8,818,370
60 - 70N	1,118,797	7,715	1,102	7,757	1,369	1,231	3,535,399	1,379,477
70 - 80N	15,450	102	15	104	18	17	48,822	19,050
80 - 90N	0	0	0	0	0	0	0	0
				1	0			

CASE B4-SUB87
CURRENT SUBSONIC FLEET (YEAR 1987)

37,000 FT ALTITUDE	TOTAL FUEL LBS/DAY	TOTAL CO LBS/DAY	TOTAL HC LBS/DAY	TOTAL NO LBS/DAY	TOTAL NO2 LBS/DAY	TOTAL SO2 LBS/DAY	TOTAL CO2 LBS/DAY	TOTAL H2O LBS/DAY
80 - 90S	0	0	0	0	0	0	0	0
70 - 80S	0	0	0	0	0	0	0	0
60 - 70S	10,205	11	2	163	29	11	32,249	12,583
50 - 60S	66,415	251	39	779	138	73	209,872	81,890
40 - 50S	418,255	1,830	282	4,552	803	460	1,321,686	515,708
30 - 40S	6,745,023	21,531	3,302	81,804	14,436	7,420	21,314,274	8,316,614
20 - 30S	6,585,794	21,608	3,785	81,508	14,384	7,244	20,811,110	8,120,285
10 - 20S	7,974,277	24,005	4,358	93,566	16,512	8,772	25,198,714	9,832,283
0 - 10S	7,631,702	23,085	4,611	98,263	17,341	8,395	24,116,179	9,409,889
0 - 10N	10,016,776	26,651	5,774	135,612	23,932	11,018	31,653,013	12,350,685
10 - 20N	17,820,452	49,825	10,459	235,494	41,558	19,602	56,312,629	21,972,617
20 - 30N	50,015,290	140,561	25,341	645,276	113,872	55,017	158,048,315	61,668,852
30 - 40N	134,004,414	544,537	87,847	1,454,030	256,594	147,405	423,453,947	165,227,442
40 - 50N	112,792,072	394,941	64,346	1,337,795	236,081	124,071	356,422,948	139,072,625
50 - 60N	68,645,944	156,470	27,611	975,353	172,121	75,511	216,921,183	84,640,449
60 - 70N	12,629,899	25,542	4,761	183,868	32,447	13,893	39,910,479	15,572,665
70 - 80N	1,644,754	1,948	302	25,647	4,526	1,809	5,197,424	2,027,982
80 - 90N	408,779	453	70	6,485	1,144	450	1,291,743	504,025

Figure 2.3.4-1

CASE B4-SUB87
CONCORDE OPERATIONS (YEAR 1987)

55,000 FT ALTITUDE	TOTAL FUEL LBS/DAY	TOTAL CO LBS/DAY	TOTAL HC LBS/DAY	TOTAL NO LBS/DAY	TOTAL NO2 LBS/DAY	TOTAL SO2 LBS/DAY	TOTAL CO2 LBS/DAY	TOTAL H2O LBS/DAY
80 - 90S	0	0	0	0	0	0	0	0
70 - 80S	0	0	0	0	0	0	0	0
60 - 70S	0	0	0	0	0	0	0	0
50 - 60S	0	0	0	0	0	0	0	0
40 - 50S	0	0	0	0	0	0	0	0
30 - 40S	0	0	0	0	0	0	0	0
20 - 30S	0	0	0	0	0	0	0	0
10 - 20S	0	0	0	0	0	0	0	0
0 - 10S	0	0	0	0	0	0	0	0
0 - 10N	0	0	0	0	0	0	0	0
10 - 20N	0	0	0	0	0	0	0	0
20 - 30N	9,111	32	2	147	26	10	28,789	11,233
30 - 40N	22,891	80	5	370	65	25	72,337	28,225
40 - 50N	344,644	1,206	69	5,566	982	379	1,089,076	424,947
50 - 60N	559,731	1,959	112	9,040	1,595	616	1,768,751	690,149
60 - 70N	0	0	0	0	0	0	0	0
70 - 80N	0	0	0	0	0	0	0	0
80 - 90N	0	0	0	0	0	0	0	0

Figure 2.3.4-2

CASE BS-SUB2000
ESTIMATED YEAR 2000 FLEET
SUBSONIC ONLY

26,000 FT ALTITUDE	TOTAL FUEL LBS/DAY	TOTAL CO LBS/DAY	TOTAL HC LBS/DAY	TOTAL NO LBS/DAY	TOTAL NO2 LBS/DAY	TOTAL SO2 LBS/DAY	TOTAL CO2 LBS/DAY	TOTAL H2O LBS/DAY
80 - 90S	0	0	0	0	0	0	0	0
70 - 80S	0	0	0	0	0	0	0	0
60 - 70S	0	0	0	0	0	0	0	0
50 - 60S	13,547	54	17	135	24	15	42,810	16,704
40 - 50S	306,667	1,655	247	2,333	412	337	969,068	378,121
30 - 40S	1,276,271	5,056	749	10,838	1,913	1,404	4,033,016	1,573,642
20 - 30S	1,649,150	4,194	659	17,892	3,157	1,814	5,211,315	2,033,402
10 - 20S	493,155	2,373	355	3,976	702	542	1,558,370	608,060
0 - 10S	1,139,678	5,053	766	9,741	1,719	1,254	3,601,383	1,405,223
0 - 10N	1,899,748	5,016	858	19,631	3,464	2,090	6,003,205	2,342,390
10 - 20N	2,900,201	7,678	1,476	30,005	5,295	3,190	9,164,635	3,575,948
20 - 30N	5,920,631	21,997	3,478	54,052	9,539	6,513	18,709,194	7,300,138
30 - 40N	33,702,143	116,596	20,553	317,424	56,016	37,072	106,498,772	41,554,742
40 - 50N	21,461,582	73,934	13,140	203,939	35,989	23,608	67,818,601	26,462,131
50 - 60N	7,981,522	23,075	3,730	82,706	14,595	8,780	25,221,609	9,841,216
60 - 70N	1,032,029	4,758	782	8,945	1,579	1,135	3,261,211	1,272,491
70 - 80N	13,991	85	13	93	16	15	44,211	17,251
80 - 90N	0	0	0	0	0	0	0	0

37,000 FT. ALTITUDE	TOTAL FUEL LBS/DAY	TOTAL CO LBS/DAY	TOTAL HC LBS/DAY	TOTAL NO LBS/DAY	TOTAL NO2 LBS/DAY	TOTAL SO2 LBS/DAY	TOTAL CO2 LBS/DAY	TOTAL H2O LBS/DAY
80 - 90S	0	0	0	0	0	0	0	0
70 - 80S	0	0	0	0	0	0	0	0
60 - 70S	10,678	12	2	151	27	12	33,744	13,167
50 - 60S	55,241	128	25	676	119	61	174,563	68,113
40 - 50S	661,263	1,261	244	8,029	1,417	727	2,089,591	815,337
30 - 40S	10,610,052	19,492	3,099	127,934	22,577	11,671	33,527,765	13,082,194
20 - 30S	9,163,969	16,629	2,673	114,024	20,122	10,080	28,958,143	11,299,174
10 - 20S	8,911,793	14,582	2,444	115,411	20,367	9,803	28,161,267	10,988,241
0 - 10S	9,511,437	14,749	2,646	125,114	22,079	10,463	30,056,140	11,727,601
0 - 10N	13,975,882	17,945	3,435	190,674	33,648	15,373	44,163,788	17,232,263
10 - 20N	24,193,455	32,833	6,599	318,449	56,197	26,613	76,451,317	29,830,530
20 - 30N	69,680,392	112,449	20,576	891,070	157,248	76,648	220,190,039	85,915,923
30 - 40N	190,913,235	445,408	79,747	2,169,734	382,894	210,005	603,285,822	235,396,018
40 - 50N	146,898,118	296,231	53,307	1,774,660	313,175	161,588	464,198,053	181,125,379
50 - 60N	82,482,771	111,156	19,188	1,106,733	195,306	90,731	260,645,557	101,701,257
60 - 70N	14,739,367	18,995	3,204	199,458	35,198	16,213	46,576,401	18,173,640
70 - 80N	2,193,002	2,495	425	30,261	5,340	2,412	6,930,074	2,704,045
80 - 90N	486,632	537	91	6,770	1,195	535	1,537,757	600,017

Figure 2.3.4-3

CASE B[illegible]-SUB[illegible]
ESTIMATED YEAR 2015 FLEET
SUBSONIC ONLY

26,000 FT ALTITUDE	TOTAL FUEL LBS/DAY	TOTAL CO LBS/DAY	TOTAL HC LBS/DAY	TOTAL NO LBS/DAY	TOTAL NO2 LBS/DAY	TOTAL SO2 LBS/DAY	TOTAL CO2 LBS/DAY	TOTAL H2O LBS/DAY
80 - 90S	0	0	0	0	0	0	0	0
70 - 80S	0	0	0	0	0	0	0	0
60 - 70S	0	0	0	0	0	0	0	0
50 - 60S	4,347	11	4	49	9	5	13,738	5,360
40 - 50S	187,235	221	39	2,118	374	206	591,663	230,861
30 - 40S	1,339,750	1,544	279	15,489	2,733	1,474	4,233,611	1,651,912
20 - 30S	2,039,345	2,184	401	24,704	4,359	2,243	6,444,330	2,514,512
10 - 20S	393,756	463	78	4,534	800	433	1,244,270	485,502
0 - 10S	1,093,588	1,212	232	12,863	2,270	1,203	3,455,739	1,348,394
0 - 10N	1,648,024	1,680	353	19,730	3,482	1,813	5,207,755	2,032,013
10 - 20N	2,965,604	3,152	698	35,272	6,224	3,262	9,371,309	3,656,590
20 - 30N	6,056,543	6,972	1,346	70,934	12,518	6,662	19,138,677	7,467,718
30 - 40N	47,149,591	55,044	11,209	556,223	98,157	51,865	148,992,709	58,135,446
40 - 50N	28,335,096	33,276	6,984	334,334	59,000	31,169	89,538,903	34,937,173
50 - 60N	10,665,704	11,566	2,356	128,221	22,627	11,732	33,703,626	13,150,813
60 - 70N	1,421,571	1,649	359	16,901	2,982	1,564	4,492,163	1,752,797
70 - 80N	1,568	3	0	10	2	2	4,956	1,934
80 - 90N	0	0	0	0	0	0	0	0

37,000 FT. ALTITUDE	TOTAL FUEL LBS/DAY	TOTAL CO LBS/DAY	TOTAL HC LBS/DAY	TOTAL NO LBS/DAY	TOTAL NO2 LBS/DAY	TOTAL SO2 LBS/DAY	TOTAL CO2 LBS/DAY	TOTAL H2O LBS/DAY
80 - 90S	0	0	0	0	0	0	0	0
70 - 80S	0	0	0	0	0	0	0	0
60 - 70S	19,399	20	4	237	42	21	61,300	23,919
50 - 60S	71,992	79	16	870	154	79	227,494	88,766
40 - 50S	1,371,083	1,415	288	16,709	2,949	1,508	4,332,621	1,690,545
30 - 40S	18,606,920	19,365	3,709	226,827	40,028	20,468	58,797,867	22,942,332
20 - 30S	14,747,562	15,355	2,913	181,413	32,014	16,222	46,602,294	18,183,743
10 - 20S	14,866,724	15,322	2,932	184,135	32,494	16,353	46,978,847	18,330,671
0 - 10S	15,393,578	15,819	3,088	191,404	33,777	16,933	48,643,708	18,980,282
0 - 10N	21,500,591	21,875	4,249	270,517	47,738	23,651	67,941,869	26,510,229
10 - 20N	33,786,901	34,080	6,781	421,177	74,325	37,166	106,766,606	41,659,248
20 - 30N	100,983,880	104,330	20,513	1,251,688	220,886	111,082	319,109,060	124,513,124
30 - 40N	289,744,907	312,550	62,565	3,503,933	618,341	318,719	915,593,906	357,255,470
40 - 50N	230,043,931	243,958	48,884	2,801,893	494,452	253,048	726,938,822	283,644,167
50 - 60N	143,452,197	146,976	29,080	1,762,616	311,050	157,797	453,308,943	176,876,559
60 - 70N	26,050,875	26,792	5,293	319,096	56,311	28,656	82,320,766	32,120,729
70 - 80N	3,733,029	3,811	750	45,824	8,087	4,106	11,796,370	4,602,824
80 - 90N	886,048	908	178	10,856	1,916	975	2,799,911	1,092,497

Figure 2.3.4-4

CASE 57-SUP2.4-SUB0.9
YEAR 2015 SUB/SUPERSONIC MIX

26,000 FT ALTITUDE

	TOTAL FUEL LBS.DAY	TOTAL CO LBS.DAY	TOTAL HC LBS.DAY	TOTAL NO LBS.DAY	TOTAL NO2 LBS.DAY	TOTAL SO2 LBS.DAY	TOTAL CO2 LBS.DAY	TOTAL H2O LBS.DAY
80 - 90S	0	0	0	0	0	0	0	0
70 - 80S	0	0	0	0	0	0	0	0
60 - 70S	0	0	0	0	0	0	0	0
50 - 60S	4,347	11	4	49	9	5	13,738	5,360
40 - 50S	177,186	211	37	1,995	352	195	559,908	218,470
30 - 40S	1,273,059	1,478	266	14,673	2,589	1,400	4,022,868	1,569,682
20 - 30S	1,729,050	1,874	339	20,906	3,689	1,902	5,463,799	2,131,919
10 - 20S	374,106	443	74	4,294	758	412	1,182,176	461,273
0 - 10S	1,051,107	1,170	224	12,343	2,178	1,156	3,321,497	1,296,014
0 - 10N	1,605,691	1,638	344	19,212	3,390	1,766	5,073,984	1,979,817
10 - 20N	2,850,944	3,037	675	33,868	5,977	3,136	9,008,982	3,515,213
20 - 30N	5,855,594	6,771	1,306	68,474	12,084	6,441	18,503,678	7,219,948
30 - 40N	44,273,969	52,168	10,634	521,025	91,946	48,701	139,905,743	54,589,804
40 - 50N	27,535,495	32,476	6,824	324,547	57,273	30,289	87,012,165	33,951,266
50 - 60N	10,294,484	11,194	2,282	123,677	21,825	11,324	32,530,569	12,693,099
60 - 70N	1,373,879	1,601	349	16,317	2,879	1,511	4,341,456	1,693,992
70 - 80N	1,568	3	0	10	2	2	4,956	1,934
80 - 90N	0	0	0	0	0	0	0	0

37,000 FT. ALTITUDE

	TOTAL FUEL LBS.DAY	TOTAL CO LBS.DAY	TOTAL HC LBS.DAY	TOTAL NO LBS.DAY	TOTAL NO2 LBS.DAY	TOTAL SO2 LBS.DAY	TOTAL CO2 LBS.DAY	TOTAL H2O LBS.DAY
80 - 90S	0	0	0	0	0	0	0	0
70 - 80S	0	0	0	0	0	0	0	0
60 - 70S	12,173	13	2	149	26	13	38,468	15,010
50 - 60S	47,155	54	11	566	100	52	149,009	58,142
40 - 50S	1,164,673	1,209	247	14,183	2,503	1,281	3,680,367	1,436,042
30 - 40S	15,946,333	30,132	4,449	186,513	32,914	17,470	50,390,413	19,661,829
20 - 30S	13,722,846	54,007	6,467	145,974	25,760	14,886	43,364,194	16,920,269
10 - 20S	12,888,538	38,331	4,903	145,503	25,677	14,046	40,727,779	15,891,567
0 - 10S	14,831,877	68,398	8,011	153,861	27,152	16,035	46,868,732	18,287,704
0 - 10N	18,226,228	51,943	6,752	211,197	37,270	19,873	57,594,879	22,472,939
10 - 20N	29,438,086	87,637	11,397	334,530	59,035	32,077	93,024,352	36,297,160
20 - 30N	107,946,083	611,304	69,274	1,048,346	185,002	116,109	341,109,624	133,097,521
30 - 40N	289,033,683	917,871	119,837	3,145,483	555,085	314,747	913,346,438	356,378,531
40 - 50N	241,418,628	1,211,645	141,757	2,389,226	421,628	260,527	762,882,865	297,669,168
50 - 60N	120,814,866	369,644	47,792	1,343,968	237,171	131,605	381,774,976	148,964,730
60 - 70N	23,263,847	116,279	13,477	231,732	40,894	25,105	73,513,758	28,684,324
70 - 80N	2,637,407	4,450	695	31,413	5,544	2,892	8,334,207	3,251,923
80 - 90N	583,577	605	118	7,154	1,262	642	1,844,103	719,550

Figure 2.3.4-5

CASE B7-SUP2.4/SUB0.9
60,000 FT. ALTITUDE

	TOTAL FUEL LBS.DAY	TOTAL CO LBS.DAY	TOTAL HC LBS.DAY	TOTAL NO LBS.DAY	TOTAL NO2 LBS.DAY	TOTAL SO2 LBS.DAY	TOTAL CO2 LBS.DAY	TOTAL H2O LBS.DAY
80 - 90S	0	0	0	0	0	0	0	0
70 - 80S	0	0	0	0	0	0	0	0
60 - 70S	0	0	0	0	0	0	0	0
50 - 60S	0	0	0	0	0	0	0	0
40 - 50S	14,463	43	4	61	11	14	45,704	17,833
30 - 40S	11,176,961	33,531	3,353	47,502	8,383	11,177	35,319,196	13,781,193
20 - 30S	7,460,482	22,381	2,238	31,707	5,595	7,460	23,575,123	9,198,774
10 - 20S	8,935,920	26,808	2,681	37,978	6,702	8,936	28,237,507	11,017,989
0 - 10S	8,768,600	26,306	2,631	37,267	6,576	8,769	27,708,775	10,811,684
0 - 10N	35,792,923	107,379	10,738	152,120	26,845	35,793	113,105,638	44,132,675
10 - 20N	34,317,679	102,953	10,295	145,850	25,738	34,318	108,443,866	42,313,698
20 - 30N	33,785,199	101,356	10,136	143,587	25,339	33,785	106,761,228	41,657,150
30 - 40N	63,040,965	189,123	18,912	267,924	47,281	63,041	199,209,451	77,729,510
40 - 50N	123,088,757	369,266	36,927	523,127	92,317	123,089	388,960,473	151,768,438
50 - 60N	55,515,569	166,547	16,655	235,941	41,637	55,516	175,429,197	68,450,696
60 - 70N	5,424,582	16,274	1,627	23,054	4,068	5,425	17,141,678	6,688,509
70 - 80N	5,830,047	17,490	1,749	24,778	4,373	5,830	18,422,947	7,188,447
80 - 90N	5,063,277	15,190	1,519	21,519	3,797	5,063	15,999,956	6,243,021

Figure 2.3.4-6

NOTE: ***Per the ICAO definition, NOx is defined as the sum of the amounts of nitric oxide and nitrogen dioxide contained in a gas sample calculated as if the nitric oxide were in the form of nitrogen dioxide. Consistent with this definition, the emission scenario columns marked as Total NO (lbs/day) refers to the weight of NO_2 which would be produced if the NO emissions were oxidized to NO_2.***

CASE B8-SUP2.4/SUB1.9
YEAR 2015 SUB/SUPERSONIC MIX

26,000 FT ALTITUDE	TOTAL FUEL LBS.DAY	TOTAL CO LBS.DAY	TOTAL HC LBS.DAY	TOTAL NO LBS.DAY	TOTAL NO2 LBS.DAY	TOTAL SO2 LBS.DAY	TOTAL CO2 LBS.DAY	TOTAL H2O LBS.DAY
80 - 90S	0	0	0	0	0	0	0	0
70 - 80S	0	0	0	0	0	0	0	0
60 - 70S	0	0	0	0	0	0	0	0
50 - 60S	4,347	11	4	49	9	5	13,738	5,360
40 - 50S	177,186	211	37	1,995	352	195	559,908	218,470
30 - 40S	1,273,059	1,478	266	14,673	2,589	1,400	4,022,868	1,569,682
20 - 30S	1,729,050	1,874	339	20,906	3,689	1,902	5,463,799	2,131,919
10 - 20S	374,106	443	74	4,294	758	412	1,182,176	461,273
0 - 10S	1,051,107	1,170	224	12,343	2,178	1,156	3,321,497	1,296,014
0 - 10N	1,605,691	1,638	344	19,212	3,390	1,766	5,073,984	1,979,817
10 - 20N	2,850,944	3,037	675	33,868	5,977	3,136	9,008,982	3,515,213
20 - 30N	5,855,594	6,771	1,306	68,474	12,084	6,441	18,503,678	7,219,948
30 - 40N	44,273,969	52,168	10,634	521,025	91,946	48,701	139,905,743	54,589,804
40 - 50N	27,535,495	32,476	6,824	324,547	57,273	30,289	87,012,165	33,951,266
50 - 60N	10,294,484	11,194	2,282	123,677	21,825	11,324	32,530,569	12,693,099
60 - 70N	1,373,879	1,601	349	16,317	2,879	1,511	4,341,456	1,693,992
70 - 80N	1,568	3	0	10	2	2	4,956	1,934
80 - 90N	0	0	0	0	0	0	0	0

37,000 FT. ALTITUDE	TOTAL FUEL LBS.DAY	TOTAL CO LBS.DAY	TOTAL HC LBS.DAY	TOTAL NO LBS.DAY	TOTAL NO2 LBS.DAY	TOTAL SO2 LBS.DAY	TOTAL CO2 LBS.DAY	TOTAL H2O LBS.DAY
80 - 90S	0	0	0	0	0	0	0	0
70 - 80S	0	0	0	0	0	0	0	0
60 - 70S	12,173	13	2	149	26	13	38,468	15,010
50 - 60S	47,155	54	11	566	100	52	149,009	58,142
40 - 50S	1,164,673	1,209	247	14,183	2,503	1,281	3,680,367	1,436,042
30 - 40S	16,023,195	99,841	6,796	187,610	33,108	17,704	50,627,810	19,763,651
20 - 30S	13,949,957	259,982	13,404	149,215	26,332	15,576	44,065,656	17,221,135
10 - 20S	13,031,565	168,048	9,272	147,544	26,037	14,481	41,169,538	16,081,042
0 - 10S	15,136,064	344,277	17,302	158,202	27,918	16,960	47,808,256	18,690,677
0 - 10N	18,417,082	225,036	12,582	213,921	37,751	20,453	58,184,359	22,725,773
10 - 20N	29,769,549	388,254	21,521	339,261	59,870	33,084	94,048,121	36,736,267
20 - 30N	110,808,213	3,207,077	156,699	1,089,198	192,211	124,807	349,949,702	136,889,133
30 - 40N	292,502,686	4,064,042	225,798	3,194,997	563,823	325,289	924,060,931	360,974,101
40 - 50N	246,892,682	6,176,273	308,962	2,467,359	435,416	277,163	779,790,230	304,920,933
50 - 60N	122,219,026	1,643,130	90,682	1,364,010	240,708	135,872	386,111,917	150,824,894
60 - 70N	23,792,031	595,308	29,611	239,271	42,224	26,710	75,145,124	29,384,036
70 - 80N	2,647,333	13,451	998	31,555	5,569	2,922	8,364,862	3,265,072
80 - 90N	583,577	605	118	7,154	1,262	642	1,844,103	719,550

Figure 2.3.4-7

CASE [illegible]
58,500 FT. ALTITUDE

	TOTAL FUEL LBS.DAY	TOTAL CO LBS.DAY	TOTAL HC LBS.DAY	TOTAL NO LBS.DAY	TOTAL NO2 LBS.DAY	TOTAL SO2 LBS.DAY	TOTAL CO2 LBS.DAY	TOTAL H2O LBS.DAY
80 - 90S	0	0	0	0	0	0	0	0
70 - 80S	0	0	0	0	0	0	0	0
60 - 70S	0	0	0	0	0	0	0	0
50 - 60S	0	0	0	0	0	0	0	0
40 - 50S	16,354	114	2	125	22	20	51,563	20,311
30 - 40S	12,637,648	88,464	1,264	96,678	17,061	15,165	39,846,504	15,695,959
20 - 30S	8,435,472	59,048	844	64,531	11,388	10,123	26,597,044	10,476,856
10 - 20S	10,103,731	70,726	1,010	77,294	13,640	12,124	31,857,065	12,548,834
0 - 10S	9,914,545	69,402	991	75,846	13,385	11,897	31,260,559	12,313,864
0 - 10N	40,470,605	283,294	4,047	309,600	54,635	48,565	127,603,816	50,264,491
10 - 20N	38,802,564	271,618	3,880	296,840	52,383	46,563	122,344,486	48,192,785
20 - 30N	38,200,496	267,403	3,820	292,234	51,571	45,841	120,446,163	47,445,016
30 - 40N	71,279,620	498,957	7,128	545,289	96,227	85,536	224,744,642	88,529,288
40 - 50N	139,174,897	974,224	13,917	1,064,688	187,886	167,010	438,818,450	172,855,222
50 - 60N	62,770,749	439,395	6,277	480,196	84,741	75,325	197,916,173	77,961,271
60 - 70N	6,133,506	42,935	613	46,921	8,280	7,360	19,338,944	7,617,814
70 - 80N	6,591,960	46,144	659	50,428	8,899	7,910	20,784,449	8,187,214
80 - 90N	5,724,983	40,075	572	43,796	7,729	6,870	18,050,873	7,110,429

Figure 2.3.4-8

CASE [illegible]
YEAR [illegible] SUB SUPERSONIC MIX

26,000 FT ALTITUDE	TOTAL FUEL LBS.DAY	TOTAL CO LBS.DAY	TOTAL HC LBS.DAY	TOTAL NO LBS.DAY	TOTAL NO2 LBS.DAY	TOTAL SO2 LBS.DAY	TOTAL CO2 LBS.DAY	TOTAL H2O LBS.DAY
80 - 90S	0	0	0	0	0	0	0	0
70 - 80S	0	0	0	0	0	0	0	0
60 - 70S	0	0	0	0	0	0	0	0
50 - 60S	4,347	11	4	49	9	5	13,738	5,360
40 - 50S	177,186	211	37	1,995	352	195	559,908	218,470
30 - 40S	1,273,059	1,478	266	14,673	2,589	1,400	4,022,868	1,569,682
20 - 30S	1,729,050	1,874	339	20,906	3,689	1,902	5,463,799	2,131,919
10 - 20S	374,106	443	74	4,294	758	412	1,182,176	461,273
0 - 10S	1,051,107	1,170	224	12,343	2,178	1,156	3,321,497	1,296,014
0 - 10N	1,605,691	1,638	344	19,212	3,390	1,766	5,073,984	1,979,817
10 - 20N	2,850,944	3,037	675	33,868	5,977	3,136	9,008,982	3,515,213
20 - 30N	5,855,594	6,771	1,306	68,474	12,084	6,441	18,503,678	7,219,948
30 - 40N	44,273,969	52,168	10,634	521,025	91,946	48,701	139,905,743	54,589,804
40 - 50N	27,535,495	32,476	6,824	324,547	57,273	30,289	87,012,165	33,951,266
50 - 60N	10,294,484	11,194	2,282	123,677	21,825	11,324	32,530,569	12,693,099
60 - 70N	1,373,879	1,601	349	16,317	2,879	1,511	4,341,456	1,693,992
70 - 80N	1,568	3	0	10	2	2	4,956	1,934
80 - 90N	0	0	0	0	0	0	0	0

37,000 FT. ALTITUDE	TOTAL FUEL LBS.DAY	TOTAL CO LBS.DAY	TOTAL HC LBS.DAY	TOTAL NO LBS.DAY	TOTAL NO2 LBS.DAY	TOTAL SO2 LBS.DAY	TOTAL CO2 LBS.DAY	TOTAL H2O LBS.DAY
80 - 90S	0	0	0	0	0	0	0	0
70 - 80S	0	0	0	0	0	0	0	0
60 - 70S	12,173	13	2	149	26	13	38,468	15,010
50 - 60S	47,155	54	11	566	100	52	149,009	58,142
40 - 50S	1,164,673	1,209	247	14,183	2,503	1,281	3,680,367	1,436,042
30 - 40S	15,932,729	29,860	4,421	186,495	32,911	17,457	50,347,425	19,645,055
20 - 30S	13,682,650	53,203	6,386	145,922	25,751	14,846	43,237,173	16,870,707
10 - 20S	12,863,223	37,825	4,853	145,470	25,671	14,021	40,647,785	15,860,354
0 - 10S	14,778,039	67,322	7,903	153,792	27,140	15,982	46,698,602	18,221,322
0 - 10N	18,192,448	51,268	6,685	211,154	37,262	19,840	57,488,136	22,431,288
10 - 20N	29,379,420	86,464	11,280	334,455	59,021	32,018	92,838,968	36,224,825
20 - 30N	107,439,512	601,172	68,261	1,047,700	184,888	115,602	339,508,858	132,472,918
30 - 40N	288,419,700	905,591	118,609	3,144,700	554,947	314,133	911,406,251	355,621,490
40 - 50N	240,449,769	1,192,268	139,819	2,387,991	421,410	259,558	759,821,270	296,474,565
50 - 60N	120,566,342	364,674	47,295	1,343,651	237,115	131,357	380,989,641	148,658,300
60 - 70N	23,170,364	114,409	13,290	231,612	40,873	25,011	73,218,349	28,569,058
70 - 80N	2,635,650	4,414	692	31,411	5,543	2,890	8,328,655	3,249,757
80 - 90N	583,577	605	118	7,154	1,262	642	1,844,103	719,550

Figure 2.3.4-9

CASE B9-SUP?.1, SUBC.-
56,700 FT. ALTITUDE

	TOTAL FUEL LBS.DAY	TOTAL CO LBS.DAY	TOTAL HC LBS.DAY	TOTAL NO LBS.DAY	TOTAL NO2 LBS.DAY	TOTAL SO2 LBS.DAY	TOTAL CO2 LBS.DAY	TOTAL H2O LBS.DAY
80 - 90S	0	0	0	0	0	0	0	0
70 - 80S	0	0	0	0	0	0	0	0
60 - 70S	0	0	0	0	0	0	0	0
50 - 60S	0	0	0	0	0	0	0	0
40 - 50S	15,052	45	5	64	11	15	47,565	18,559
30 - 40S	11,632,114	34,896	3,490	49,436	8,724	11,632	36,757,481	14,342,397
20 - 30S	7,764,293	23,293	2,329	32,998	5,823	7,764	24,535,165	9,573,373
10 - 20S	9,299,814	27,899	2,790	39,524	6,975	9,300	29,387,413	11,466,671
0 - 10S	9,125,688	27,377	2,738	38,784	6,844	9,126	28,837,173	11,251,973
0 - 10N	37,250,488	111,751	11,175	158,315	27,938	37,250	117,711,541	45,929,851
10 - 20N	35,715,194	107,146	10,715	151,790	26,786	35,715	112,860,012	44,036,834
20 - 30N	35,161,034	105,483	10,548	149,434	26,371	35,161	111,108,868	43,353,555
30 - 40N	65,607,952	196,824	19,682	278,834	49,206	65,608	207,321,129	80,894,605
40 - 50N	128,100,819	384,302	38,430	544,428	96,076	128,101	404,798,589	157,948,310
50 - 60N	57,776,151	173,328	17,333	245,549	43,332	57,776	182,572,638	71,237,995
60 - 70N	5,645,494	16,936	1,694	23,993	4,234	5,645	17,839,761	6,960,894
70 - 80N	6,067,460	18,202	1,820	25,787	4,551	6,067	19,173,175	7,481,179
80 - 90N	5,269,472	15,808	1,581	22,395	3,952	5,269	16,651,533	6,497,259

Figure 2.3.4-10

CASE B10-SUP2.4/SUP1.5
YEAR 2015 SUB/SUPERSONIC MIX

26,000 FT ALTITUDE	TOTAL FUEL LBS.DAY	TOTAL CO LBS.DAY	TOTAL HC LBS.DAY	TOTAL NO LBS.DAY	TOTAL NO2 LBS.DAY	TOTAL SO2 LBS.DAY	TOTAL CO2 LBS.DAY	TOTAL H2O LBS.DAY
80 - 90S	0	0	0	0	0	0	0	0
70 - 80S	0	0	0	0	0	0	0	0
60 - 70S	0	0	0	0	0	0	0	0
50 - 60S	4,347	11	4	49	9	5	13,738	5,360
40 - 50S	177,186	211	37	1,995	352	195	559,908	218,470
30 - 40S	1,273,059	1,478	266	14,673	2,589	1,400	4,022,868	1,569,682
20 - 30S	1,729,050	1,874	339	20,906	3,689	1,902	5,463,799	2,131,919
10 - 20S	374,106	443	74	4,294	758	412	1,182,176	461,273
0 - 10S	1,051,107	1,170	224	12,343	2,178	1,156	3,321,497	1,296,014
0 - 10N	1,605,691	1,638	344	19,212	3,390	1,766	5,073,984	1,979,817
10 - 20N	2,850,944	3,037	675	33,868	5,977	3,136	9,008,982	3,515,213
20 - 30N	5,855,594	6,771	1,306	68,474	12,084	6,441	18,503,678	7,219,948
30 - 40N	44,273,969	52,168	10,634	521,025	91,946	48,701	139,905,743	54,589,804
40 - 50N	27,535,495	32,476	6,824	324,547	57,273	30,289	87,012,165	33,951,266
50 - 60N	10,294,484	11,194	2,282	123,677	21,825	11,324	32,530,569	12,693,099
60 - 70N	1,373,879	1,601	349	16,317	2,879	1,511	4,341,456	1,693,992
70 - 80N	1,568	3	0	10	2	2	4,956	1,934
80 - 90N	0	0	0	0	0	0	0	0

37,000 FT. ALTITUDE	TOTAL FUEL LBS.DAY	TOTAL CO LBS.DAY	TOTAL HC LBS.DAY	TOTAL NO LBS.DAY	TOTAL NO2 LBS.DAY	TOTAL SO2 LBS.DAY	TOTAL CO2 LBS.DAY	TOTAL H2O LBS.DAY
80 - 90S	0	0	0	0	0	0	0	0
70 - 80S	0	0	0	0	0	0	0	0
60 - 70S	12,173	13	2	149	26	13	38,468	15,010
50 - 60S	47,155	54	11	566	100	52	149,009	58,142
40 - 50S	1,164,673	1,209	247	14,183	2,503	1,281	3,680,367	1,436,042
30 - 40S	15,239,616	15,998	3,035	185,612	32,755	16,764	48,157,186	18,790,446
20 - 30S	11,634,636	12,242	2,290	143,311	25,290	12,798	36,765,449	14,345,506
10 - 20S	11,573,448	12,029	2,273	143,826	25,381	12,731	36,572,095	14,270,061
0 - 10S	12,034,970	12,460	2,417	150,295	26,523	13,238	38,030,505	14,839,118
0 - 10N	16,471,380	16,846	3,243	208,960	36,875	18,119	52,049,559	20,309,211
10 - 20N	26,390,387	26,683	5,301	330,644	58,349	29,029	83,393,623	32,539,347
20 - 30N	81,629,693	84,976	16,642	1,014,793	179,081	89,793	257,949,830	100,649,411
30 - 40N	257,137,269	279,943	56,044	3,104,815	547,909	282,851	812,553,769	317,050,252
40 - 50N	191,086,400	205,000	41,092	2,325,053	410,303	210,195	603,833,023	235,609,531
50 - 60N	107,904,050	111,428	21,970	1,327,507	234,266	118,694	340,976,798	133,045,694
60 - 70N	18,407,367	19,149	3,764	225,540	39,801	20,248	58,167,278	22,696,283
70 - 80N	2,546,147	2,624	513	31,297	5,523	2,801	8,045,823	3,139,399
80 - 90N	583,577	605	118	7,154	1,262	642	1,844,103	719,550

Figure 2.3.4-11

CASE B10-SUP2.4/SUP1.5

46,000 FT. ALTITUDE	TOTAL FUEL LBS.DAY	TOTAL CO LBS.DAY	TOTAL HC LBS.DAY	TOTAL NO LBS.DAY	TOTAL NO2 LBS.DAY	TOTAL SO2 LBS.DAY	TOTAL CO2 LBS.DAY	TOTAL H2O LBS.DAY
80 - 90S	0	0	0	0	0	0	0	0
70 - 80S	0	0	0	0	0	0	0	0
60 - 70S	0	0	0	0	0	0	0	0
50 - 60S	0	0	0	0	0	0	0	0
40 - 50S	0	0	0	0	0	0	0	0
30 - 40S	783,124	2,349	235	1,930	341	783	2,474,672	965,592
20 - 30S	2,299,489	6,898	690	5,668	1,000	2,299	7,266,385	2,835,270
10 - 20S	1,448,146	4,344	434	3,570	630	1,448	4,576,141	1,785,564
0 - 10S	3,079,893	9,240	924	7,592	1,340	3,080	9,732,461	3,797,508
0 - 10N	1,932,398	5,797	580	4,763	841	1,932	6,106,377	2,382,647
10 - 20N	3,356,067	10,068	1,007	8,273	1,460	3,356	10,605,172	4,138,031
20 - 30N	28,978,932	86,937	8,694	71,433	12,606	28,979	91,573,425	35,731,023
30 - 40N	35,123,488	105,370	10,537	86,579	15,279	35,123	110,990,223	43,307,261
40 - 50N	55,425,538	166,277	16,628	136,624	24,110	55,426	175,144,701	68,339,689
50 - 60N	14,217,041	42,651	4,265	35,045	6,184	14,217	44,925,848	17,529,611
60 - 70N	5,347,850	16,044	1,604	13,182	2,326	5,348	16,899,205	6,593,899
70 - 80N	100,494	301	30	248	44	100	317,561	123,909
80 - 90N	0	0	0	0	0	0	0	0

Figure 2.3.4-12

CASE 510-SUP2.4.SUP1.5
60,000 FT. ALTITUDE

	TOTAL FUEL LBS.DAY	TOTAL CO LBS.DAY	TOTAL HC LBS.DAY	TOTAL NO LBS.DAY	TOTAL NO2 LBS.DAY	TOTAL SO2 LBS.DAY	TOTAL CO2 LBS.DAY	TOTAL H2O LBS.DAY
80 - 90S	0	0	0	0	0	0	0	0
70 - 80S	0	0	0	0	0	0	0	0
60 - 70S	0	0	0	0	0	0	0	0
50 - 60S	0	0	0	0	0	0	0	0
40 - 50S	14,463	43	4	61	11	14	45,704	17,833
30 - 40S	11,176,961	33,531	3,353	47,502	8,383	11,177	35,319,196	13,781,193
20 - 30S	7,460,482	22,381	2,238	31,707	5,595	7,460	23,575,123	9,198,774
10 - 20S	8,935,920	26,808	2,681	37,978	6,702	8,936	28,237,507	11,017,989
0 - 10S	8,768,600	26,306	2,631	37,267	6,576	8,769	27,708,775	10,811,684
0 - 10N	35,792,923	107,379	10,738	152,120	26,845	35,793	113,105,638	44,132,675
10 - 20N	34,317,679	102,953	10,295	145,850	25,738	34,318	108,443,866	42,313,698
20 - 30N	33,785,199	101,356	10,136	143,587	25,339	33,785	106,761,228	41,657,150
30 - 40N	63,040,965	189,123	18,912	267,924	47,281	63,041	199,209,451	77,729,510
40 - 50N	123,088,757	369,266	36,927	523,127	92,317	123,089	388,960,473	151,768,438
50 - 60N	55,515,569	166,547	16,655	235,941	41,637	55,516	175,429,197	68,450,696
60 - 70N	5,424,582	16,274	1,627	23,054	4,068	5,425	17,141,678	6,688,509
70 - 80N	5,830,047	17,490	1,749	24,778	4,373	5,830	18,422,947	7,188,447
80 - 90N	5,063,277	15,190	1,519	21,519	3,797	5,063	15,999,956	6,243,021

Figure 2.3.4-13

CASE 54-SUB87
CURRENT SUBSONIC FLEET (YEAR 1987)

26,000 FT ALTITUDE	TOTAL CO MOLECULES/SEC	TOTAL HC (CH4) MOLECULES/SEC	TOTAL NO MOLECULES/SE	TOTAL NO2 MOLECULES/SEC	TOTAL SO2 MOLECULES/SE	TOTAL CO2 MOLECULES/SEC	TOTAL H2O MOLECULES/SEC
80 - 90S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
70 - 80S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
60 - 70S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
50 - 60S	1.5958E+22	4.8329E+21	1.7307E+22	1.9921E+21	1.1848E+21	4.9543E+24	4.7223E+24
40 - 50S	2.6179E+23	6.6821E+22	2.4753E+23	2.8490E+22	1.8652E+22	7.7995E+25	7.4342E+25
30 - 40S	7.8686E+23	1.9756E+23	8.3300E+23	9.5879E+22	5.9693E+22	2.4960E+26	2.3791E+26
20 - 30S	8.5472E+23	2.4147E+23	1.4565E+24	1.6765E+23	8.1172E+22	3.3942E+26	3.2352E+26
10 - 20S	6.3552E+23	2.0794E+23	4.9855E+23	5.7384E+22	3.9050E+22	1.6329E+26	1.5564E+26
0 - 10S	1.1283E+24	3.3558E+23	1.0777E+24	1.2404E+23	7.7422E+22	3.2374E+26	3.0858E+26
0 - 10N	1.2113E+24	3.2791E+23	1.4977E+24	1.7239E+23	9.7712E+22	4.0858E+26	3.8945E+26
10 - 20N	1.6698E+24	4.4119E+23	2.4313E+24	2.7984E+23	1.4657E+23	6.1286E+26	5.8416E+26
20 - 30N	3.5523E+24	9.3344E+23	4.5014E+24	5.1811E+23	2.9283E+23	1.2245E+27	1.1671E+27
30 - 40N	1.6774E+25	4.6160E+24	2.0891E+25	2.4046E+24	1.3657E+24	5.7105E+27	5.4431E+27
40 - 50N	1.3405E+25	3.4805E+24	1.6957E+25	1.9518E+24	1.0992E+24	4.5964E+27	4.3811E+27
50 - 60N	4.7227E+24	1.1627E+24	6.1351E+24	7.0615E+23	3.8833E+23	1.6238E+27	1.5478E+27
60 - 70N	8.7097E+23	2.1725E+23	8.1738E+23	9.4081E+22	6.0748E+22	2.5401E+26	2.4212E+26
70 - 80N	1.1511E+22	3.0454E+21	1.0932E+22	1.2583E+21	8.3889E+20	3.5078E+24	3.3435E+24
80 - 90N	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

CURRENT SUBSONIC FLEET (YEAR 1987)

37,000 FT ALTITUDE	TOTAL CO MOLECULES/SEC	TOTAL HC (CH4) MOLECULES/SEC	TOTAL NO MOLECULES/SE	TOTAL NO2 MOLECULES/SEC	TOTAL SO2 MOLECULES/SE	TOTAL CO2 MOLECULES/SEC	TOTAL H2O MOLECULES/SEC
80 - 90S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
70 - 80S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
60 - 70S	1.2673E+21	3.4197E+20	1.7185E+22	1.9779E+21	5.5412E+20	2.3170E+24	2.2085E+24
50 - 60S	2.8321E+22	7.6588E+21	8.2112E+22	9.4511E+21	3.6062E+21	1.5079E+25	1.4373E+25
40 - 50S	2.0656E+23	5.5664E+22	4.7964E+23	5.5207E+22	2.2710E+22	9.4962E+25	9.0514E+25
30 - 40S	2.4307E+24	6.5081E+23	8.6200E+24	9.9216E+23	3.6624E+23	1.5314E+27	1.4597E+27
20 - 30S	2.4393E+24	7.4598E+23	8.5888E+24	9.8858E+23	3.5759E+23	1.4953E+27	1.4252E+27
10 - 20S	2.7099E+24	8.5898E+23	9.8595E+24	1.1348E+24	4.3298E+23	1.8105E+27	1.7257E+27
0 - 10S	2.6061E+24	9.0898E+23	1.0354E+25	1.1918E+24	4.1438E+23	1.7327E+27	1.6516E+27
0 - 10N	3.0087E+24	1.1382E+24	1.4290E+25	1.6448E+24	5.4388E+23	2.2742E+27	2.1677E+27
10 - 20N	5.6248E+24	2.0616E+24	2.4815E+25	2.8562E+24	9.6760E+23	4.0460E+27	3.8565E+27
20 - 30N	1.5868E+25	4.9949E+24	6.7996E+25	7.8263E+24	2.7157E+24	1.1356E+28	1.0824E+28
30 - 40N	6.1473E+25	1.7316E+25	1.5322E+26	1.7635E+25	7.2761E+24	3.0425E+28	2.9000E+28
40 - 50N	4.4585E+25	1.2683E+25	1.4097E+26	1.6226E+25	6.1243E+24	2.5609E+28	2.4409E+28
50 - 60N	1.7664E+25	5.4424E+24	1.0278E+26	1.1830E+25	3.7273E+24	1.5586E+28	1.4856E+28
60 - 70N	2.8834E+24	9.3840E+23	1.9375E+25	2.2301E+24	6.8577E+23	2.8675E+27	2.7332E+27
70 - 80N	2.1986E+23	5.9434E+22	2.7026E+24	3.1106E+23	8.9306E+22	3.7343E+26	3.5594E+26
80 - 90N	5.1088E+22	1.3815E+22	6.8332E+23	7.8651E+22	2.2196E+22	9.2810E+25	8.8464E+25

Figure 2.3.4-14

CASE B4-S[illegible]987
CONCORDE OPERATIONS (YEAR 1987)

55,000 FT ALTITUDE	TOTAL CO MOLECULES/SEC	TOTAL HC (CH4) MOLECULES/SEC	TOTAL NO MOLECULES/SE	TOTAL NO2 MOLECULES/SEC	TOTAL SO2 MOLECULES/SE	TOTAL CO2 MOLECULES/SEC	TOTAL H2O MOLECULES/SEC
80 - 90S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
70 - 80S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
60 - 70S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
50 - 60S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
40 - 50S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
30 - 40S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
20 - 30S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
10 - 20S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0 - 10S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0 - 10N	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
10 - 20N	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
20 - 30N	3.5998E+21	3.5916E+20	1.5504E+22	1.7846E+21	4.9468E+20	2.0685E+24	1.9716E+24
30 - 40N	9.0448E+21	9.0244E+20	3.8957E+22	4.4839E+21	1.2429E+21	5.1973E+24	4.9539E+24
40 - 50N	1.3618E+23	1.3587E+22	5.8651E+23	6.7508E+22	1.8713E+22	7.8249E+25	7.4584E+25
50 - 60N	2.2116E+23	2.2066E+22	9.5255E+23	1.0964E+23	3.0392E+22	1.2708E+26	1.2113E+26
60 - 70N	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
70 - 80N	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
80 - 90N	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

Figure 2.3.4-15

CASE BS-SUB2000
ESTIMATED YEAR 2000 FLEET
SUBSONIC ONLY

26,000 FT ALTITUDE	TOTAL CO MOLECULES/SEC	TOTAL HC (CH4) MOLECULES/SEC	TOTAL NO MOLECULES/SEC	TOTAL NO2 MOLECULES/SEC	TOTAL SO2 MOLECULES/SEC	TOTAL CO2 MOLECULES/SEC	TOTAL H2O MOLECULES/SEC
80 - 90S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
70 - 80S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
60 - 70S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
50 - 60S	6.1157E+21	3.2902E+21	1.4273E+22	1.6428E+21	7.3559E+20	3.0758E+24	2.9318E+24
40 - 50S	1.8688E+23	4.8713E+22	2.4588E+23	2.8301E+22	1.6651E+22	6.9627E+25	6.6366E+25
30 - 40S	5.7083E+23	1.4764E+23	1.1420E+24	1.3145E+23	6.9298E+22	2.8977E+26	2.7620E+26
20 - 30S	4.7343E+23	1.2988E+23	1.8853E+24	2.1700E+23	8.9544E+22	3.7443E+26	3.5689E+26
10 - 20S	2.6794E+23	6.9945E+22	4.1892E+23	4.8218E+22	2.6777E+22	1.1197E+26	1.0672E+26
0 - 10S	5.7041E+23	1.5092E+23	1.0264E+24	1.1814E+23	6.1881E+22	2.5876E+26	2.4664E+26
0 - 10N	5.6623E+23	1.7705E+23	2.0686E+24	2.3809E+23	1.0315E+23	4.3132E+26	4.1112E+26
10 - 20N	8.6680E+23	2.9097E+23	3.1618E+24	3.6392E+23	1.5747E+23	6.5847E+26	6.2763E+26
20 - 30N	2.4832E+24	6.8564E+23	5.6957E+24	6.5557E+23	3.2147E+23	1.3442E+27	1.2813E+27
30 - 40N	1.3163E+25	4.0512E+24	3.3448E+25	3.8499E+24	1.8299E+24	7.6518E+27	7.2935E+27
40 - 50N	8.3465E+24	2.5900E+24	2.1490E+25	2.4735E+24	1.1653E+24	4.8727E+27	4.6445E+27
50 - 60N	2.6049E+24	7.3515E+23	8.7151E+24	1.0031E+24	4.3337E+23	1.8121E+27	1.7273E+27
60 - 70N	5.3714E+23	1.5407E+23	9.4258E+23	1.0849E+23	5.6036E+22	2.3431E+26	2.2334E+26
70 - 80N	9.6000E+21	2.4822E+21	9.8302E+21	1.1315E+21	7.5966E+20	3.1765E+24	3.0277E+24
80 - 90N	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

37,000 FT. ALTITUDE	TOTAL CO MOLECULES/SEC	TOTAL HC (CH4) MOLECULES/SEC	TOTAL NO MOLECULES/SEC	TOTAL NO2 MOLECULES/SEC	TOTAL SO2 MOLECULES/SEC	TOTAL CO2 MOLECULES/SEC	TOTAL H2O MOLECULES/SEC
80 - 90S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
70 - 80S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
60 - 70S	1.3289E+21	3.8430E+20	1.5870E+22	1.8267E+21	5.7981E+20	2.4245E+24	2.3109E+24
50 - 60S	1.4425E+22	4.8843E+21	7.1200E+22	8.1951E+21	2.9995E+21	1.2542E+25	1.1955E+25
40 - 50S	1.4239E+23	4.8145E+22	8.4602E+23	9.7377E+22	3.5905E+22	1.5014E+26	1.4310E+26
30 - 40S	2.2005E+24	6.1093E+23	1.3481E+25	1.5517E+24	5.7610E+23	2.4089E+27	2.2961E+27
20 - 30S	1.8773E+24	5.2697E+23	1.2015E+25	1.3830E+24	4.9758E+23	2.0806E+27	1.9832E+27
10 - 20S	1.6462E+24	4.8166E+23	1.2161E+25	1.3998E+24	4.8389E+23	2.0234E+27	1.9286E+27
0 - 10S	1.6651E+24	5.2150E+23	1.3184E+25	1.5175E+24	5.1644E+23	2.1595E+27	2.0584E+27
0 - 10N	2.0259E+24	6.7703E+23	2.0092E+25	2.3126E+24	7.5885E+23	3.1731E+27	3.0245E+27
10 - 20N	3.7065E+24	1.3008E+24	3.3556E+25	3.8623E+24	1.3136E+24	5.4930E+27	5.2357E+27
20 - 30N	1.2695E+25	4.0559E+24	9.3896E+25	1.0807E+25	3.7835E+24	1.5820E+28	1.5080E+28
30 - 40N	5.0283E+25	1.5719E+25	2.2863E+26	2.6316E+25	1.0366E+25	4.3345E+28	4.1315E+28
40 - 50N	3.3442E+25	1.0507E+25	1.8700E+26	2.1524E+25	7.9762E+24	3.3352E+28	3.1790E+28
50 - 60N	1.2549E+25	3.7822E+24	1.1662E+26	1.3423E+25	4.4786E+24	1.8727E+28	1.7850E+28
60 - 70N	2.1444E+24	6.3157E+23	2.1018E+25	2.4191E+24	8.0031E+23	3.3465E+27	3.1897E+27
70 - 80N	2.8166E+23	8.3769E+22	3.1888E+24	3.6703E+23	1.1908E+23	4.9792E+26	4.7460E+26
80 - 90N	6.0617E+22	1.7865E+22	7.1343E+23	8.2116E+22	2.6423E+22	1.1049E+26	1.0531E+26

Figure 2.3.4-16

CASE 96-SUB2015
ESTIMATED YEAR 2015 FLEET
SUBSONIC ONLY

26,000 FT ALTITUDE LATITUDE BAND	TOTAL CO MOLECULES/SEC	TOTAL HC MOLECULES/SEC	TOTAL NO MOLECULES/SEC	TOTAL NO2 MOLECULES/SEC	TOTAL SO2 MOLECULES/SEC	TOTAL CO2 MOLECULES/SEC	TOTAL H2O MOLECULES/SEC
80 - 90S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
70 - 80S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
60 - 70S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
50 - 60S	1.2447E+21	8.1418E+20	5.1122E+21	5.8842E+20	2.3605E+20	9.8705E+23	9.4082E+23
40 - 50S	2.4980E+22	7.6188E+21	2.2318E+23	2.5688E+22	1.0166E+22	4.2510E+25	4.0520E+25
30 - 40S	1.7433E+23	5.5058E+22	1.6322E+24	1.8786E+23	7.2745E+22	3.0418E+26	2.8994E+26
20 - 30S	2.4656E+23	7.8980E+22	2.6031E+24	2.9962E+23	1.1073E+23	4.6302E+26	4.4133E+26
10 - 20S	5.2242E+22	1.5286E+22	4.7780E+23	5.4995E+22	2.1380E+22	8.9400E+25	8.5213E+25
0 - 10S	1.3686E+23	4.5770E+22	1.3555E+24	1.5601E+23	5.9379E+22	2.4829E+26	2.3666E+26
0 - 10N	1.8966E+23	6.9574E+22	2.0791E+24	2.3930E+23	8.9483E+22	3.7417E+26	3.5665E+26
10 - 20N	3.5579E+23	1.3751E+23	3.7168E+24	4.2780E+23	1.6102E+23	6.7332E+26	6.4179E+26
20 - 30N	7.8710E+23	2.6535E+23	7.4746E+24	8.6033E+23	3.2885E+23	1.3751E+27	1.3107E+27
30 - 40N	6.2140E+24	2.2094E+24	5.8612E+25	6.7462E+24	2.5601E+24	1.0705E+28	1.0204E+28
40 - 50N	3.7565E+24	1.3766E+24	3.5230E+25	4.0550E+24	1.5385E+24	6.4333E+27	6.1320E+27
50 - 60N	1.3057E+24	4.6439E+23	1.3511E+25	1.5551E+24	5.7912E+23	2.4216E+27	2.3082E+27
60 - 70N	1.8611E+23	7.0687E+22	1.7809E+24	2.0498E+23	7.7187E+22	3.2276E+26	3.0764E+26
70 - 80N	3.3637E+20	3.0911E+19	1.0394E+21	1.1964E+20	8.5149E+19	3.5605E+23	3.3937E+23
80 - 90N	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

37,000 FT. ALTITUDE LATITUDE BAND	TOTAL CO MOLECULES/SEC	TOTAL HC MOLECULES/SEC	TOTAL NO MOLECULES/SEC	TOTAL NO2 MOLECULES/SEC	TOTAL SO2 MOLECULES/SEC	TOTAL CO2 MOLECULES/SEC	TOTAL H2O MOLECULES/SEC
80 - 90S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
70 - 80S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
60 - 70S	2.2532E+21	7.6966E+20	2.4998E+22	2.8773E+21	1.0533E+21	4.4044E+24	4.1981E+24
50 - 60S	8.9042E+21	3.2018E+21	9.1724E+22	1.0557E+22	3.9090E+21	1.6345E+25	1.5580E+25
40 - 50S	1.5978E+23	5.6756E+22	1.7607E+24	2.0266E+23	7.4446E+22	3.1129E+26	2.9672E+26
30 - 40S	2.1861E+24	7.3104E+23	2.3902E+25	2.7511E+24	1.0103E+24	4.2246E+27	4.0267E+27
20 - 30S	1.7335E+24	5.7412E+23	1.9116E+25	2.2003E+24	8.0075E+23	3.3483E+27	3.1915E+27
10 - 20S	1.7297E+24	5.7791E+23	1.9403E+25	2.2333E+24	8.0722E+23	3.3754E+27	3.2173E+27
0 - 10S	1.7858E+24	6.0877E+23	2.0169E+25	2.3215E+24	8.3583E+23	3.4950E+27	3.3313E+27
0 - 10N	2.4695E+24	8.3746E+23	2.8506E+25	3.2810E+24	1.1674E+24	4.8816E+27	4.6529E+27
10 - 20N	3.8473E+24	1.3366E+24	4.4381E+25	5.1083E+24	1.8345E+24	7.6711E+27	7.3118E+27
20 - 30N	1.1778E+25	4.0433E+24	1.3190E+26	1.5181E+25	5.4831E+24	2.2928E+28	2.1854E+28
30 - 40N	3.5284E+25	1.2332E+25	3.6922E+26	4.2498E+25	1.5732E+25	6.5785E+28	6.2704E+28
40 - 50N	2.7541E+25	9.6356E+24	2.9525E+26	3.3983E+25	1.2491E+25	5.2230E+28	4.9784E+28
50 - 60N	1.6592E+25	5.7320E+24	1.8573E+26	2.1378E+25	7.7891E+24	3.2570E+28	3.1044E+28
60 - 70N	3.0246E+24	1.0433E+24	3.3625E+25	3.8702E+24	1.4145E+24	5.9147E+27	5.6377E+27
70 - 80N	4.3026E+23	1.4783E+23	4.8287E+24	5.5579E+23	2.0269E+23	8.4756E+26	8.0786E+26
80 - 90N	1.0245E+23	3.5102E+22	1.1440E+24	1.3167E+23	4.8110E+22	2.0117E+26	1.9175E+26

Figure 2.3.4-17

CASE B7-SUP2.4/SUB0.9
YEAR 2015 SUB/SUPERSONIC MIX

26,000 FT ALTITUDE	TOTAL CO MOLECULES/SEC	TOTAL HC (CH4) MOLECULES/SEC	TOTAL NO MOLECULES/SEC	TOTAL NO2 MOLECULES/SEC	TOTAL SO2 MOLECULES/SEC	TOTAL CO2 MOLECULES/SEC	TOTAL H2O MOLECULES/SEC
80 - 90S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
70 - 80S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
60 - 70S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
50 - 60S	1.2447E+21	8.1418E+20	5.1122E+21	5.8842E+20	2.3605E+20	9.8705E+23	9.4082E+23
40 - 50S	2.3846E+22	7.2227E+21	2.1022E+23	2.4196E+22	9.6207E+21	4.0229E+25	3.8345E+25
30 - 40S	1.6680E+23	5.2428E+22	1.5461E+24	1.7796E+23	6.9124E+22	2.8904E+26	2.7550E+26
20 - 30S	2.1153E+23	6.6748E+22	2.2029E+24	2.5356E+23	9.3883E+22	3.9257E+26	3.7418E+26
10 - 20S	5.0024E+22	1.4511E+22	4.5245E+23	5.2077E+22	2.0313E+22	8.4938E+25	8.0960E+25
0 - 10S	1.3207E+23	4.4095E+22	1.3007E+24	1.4971E+23	5.7072E+22	2.3865E+26	2.2747E+26
0 - 10N	1.8488E+23	6.7905E+22	2.0245E+24	2.3302E+23	8.7185E+22	3.6456E+26	3.4749E+26
10 - 20N	3.4285E+23	1.3299E+23	3.5689E+24	4.1078E+23	1.5480E+23	6.4729E+26	6.1697E+26
20 - 30N	7.6441E+23	2.5743E+23	7.2154E+24	8.3050E+23	3.1794E+23	1.3295E+27	1.2672E+27
30 - 40N	5.8893E+24	2.0960E+24	5.4903E+25	6.3193E+24	2.4040E+24	1.0052E+28	9.5813E+27
40 - 50N	3.6663E+24	1.3451E+24	3.4199E+25	3.9363E+24	1.4951E+24	6.2517E+27	5.9590E+27
50 - 60N	1.2638E+24	4.4976E+23	1.3032E+25	1.5000E+24	5.5896E+23	2.3373E+27	2.2278E+27
60 - 70N	1.8072E+23	6.8807E+22	1.7194E+24	1.9790E+23	7.4598E+22	3.1193E+26	2.9732E+26
70 - 80N	3.3637E+20	3.0911E+19	1.0394E+21	1.1964E+20	8.5149E+19	3.5605E+23	3.3937E+23
80 - 90N	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

37,000 FT. ALTITUDE	TOTAL CO MOLECULES/SEC	TOTAL HC (CH4) MOLECULES/SEC	TOTAL NO MOLECULES/SEC	TOTAL NO2 MOLECULES/SEC	TOTAL SO2 MOLECULES/SEC	TOTAL CO2 MOLECULES/SEC	TOTAL H2O MOLECULES/SEC
80 - 90S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
70 - 80S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
60 - 70S	1.4375E+21	4.8482E+20	1.5679E+22	1.8046E+21	6.6098E+20	2.7639E+24	2.6345E+24
50 - 60S	6.1003E+21	2.2227E+21	5.9689E+22	6.8702E+21	2.5604E+21	1.0706E+25	1.0205E+25
40 - 50S	1.3648E+23	4.8619E+22	1.4945E+24	1.7202E+23	6.3239E+22	2.6443E+26	2.5205E+26
30 - 40S	3.4016E+24	8.7689E+23	1.9654E+25	2.2621E+24	8.6235E+23	3.6205E+27	3.4509E+27
20 - 30S	6.0969E+24	1.2746E+24	1.5382E+25	1.7705E+24	7.3481E+23	3.1157E+27	2.9698E+27
10 - 20S	4.3272E+24	9.6652E+23	1.5332E+25	1.7647E+24	6.9332E+23	2.9263E+27	2.7892E+27
0 - 10S	7.7215E+24	1.5790E+24	1.6213E+25	1.8661E+24	7.9152E+23	3.3675E+27	3.2098E+27
0 - 10N	5.8639E+24	1.3310E+24	2.2255E+25	2.5615E+24	9.8097E+23	4.1381E+27	3.9443E+27
10 - 20N	9.8935E+24	2.2465E+24	3.5251E+25	4.0574E+24	1.5834E+24	6.6837E+27	6.3707E+27
20 - 30N	6.9011E+25	1.3655E+25	1.1047E+26	1.2715E+25	5.7313E+24	2.4508E+28	2.3361E+28
30 - 40N	1.0362E+26	2.3621E+25	3.3145E+26	3.8150E+25	1.5536E+25	6.5623E+28	6.2550E+28
40 - 50N	1.3678E+26	2.7942E+25	2.5176E+26	2.8978E+25	1.2860E+25	5.4812E+28	5.2245E+28
50 - 60N	4.1729E+25	9.4203E+24	1.4162E+26	1.6300E+25	6.4962E+24	2.7430E+28	2.6146E+28
60 - 70N	1.3127E+25	2.6565E+24	2.4419E+25	2.8106E+24	1.2392E+24	5.2819E+27	5.0345E+27
70 - 80N	5.0232E+23	1.3702E+23	3.3102E+24	3.8100E+23	1.4275E+23	5.9880E+26	5.7076E+26
80 - 90N	6.8304E+22	2.3178E+22	7.5384E+23	8.6767E+22	3.1687E+22	1.3250E+26	1.2629E+26

Figure 2.3.4-18

CASE B7-SUP2.4/SUB0.9
60,000 FT. ALTITUDE

	TOTAL CO MOLECULES/SEC	TOTAL HC (CH4) MOLECULES/SEC	TOTAL NO MOLECULES/SEC	TOTAL NO2 MOLECULES/SEC	TOTAL SO2 MOLECULES/SEC	TOTAL CO2 MOLECULES/SEC	TOTAL H2O MOLECULES/SEC
80 - 90S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
70 - 80S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
60 - 70S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
50 - 60S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
40 - 50S	4.8983E+21	8.5527E+20	6.4773E+21	7.4554E+20	7.1393E+20	3.2838E+24	3.1300E+24
30 - 40S	3.7853E+24	6.6093E+23	5.0055E+24	5.7613E+23	5.5171E+23	2.5376E+27	2.4188E+27
20 - 30S	2.5267E+24	4.4117E+23	3.3411E+24	3.8456E+23	3.6826E+23	1.6938E+27	1.6145E+27
10 - 20S	3.0264E+24	5.2841E+23	4.0019E+24	4.6062E+23	4.4109E+23	2.0288E+27	1.9338E+27
0 - 10S	2.9697E+24	5.1852E+23	3.9269E+24	4.5199E+23	4.3283E+23	1.9908E+27	1.8976E+27
0 - 10N	1.2122E+25	2.1166E+24	1.6030E+25	1.8450E+24	1.7668E+24	8.1265E+27	7.7459E+27
10 - 20N	1.1622E+25	2.0293E+24	1.5369E+25	1.7690E+24	1.6940E+24	7.7916E+27	7.4267E+27
20 - 30N	1.1442E+25	1.9978E+24	1.5130E+25	1.7415E+24	1.6677E+24	7.6707E+27	7.3114E+27
30 - 40N	2.1350E+25	3.7278E+24	2.8232E+25	3.2495E+24	3.1118E+24	1.4313E+28	1.3643E+28
40 - 50N	4.1687E+25	7.2787E+24	5.5124E+25	6.3448E+24	6.0758E+24	2.7946E+28	2.6638E+28
50 - 60N	1.8802E+25	3.2828E+24	2.4862E+25	2.8616E+24	2.7403E+24	1.2604E+28	1.2014E+28
60 - 70N	1.8372E+24	3.2078E+23	2.4294E+24	2.7962E+23	2.6776E+23	1.2316E+27	1.1739E+27
70 - 80N	1.9745E+24	3.4475E+23	2.6109E+24	3.0052E+23	2.8778E+23	1.3237E+27	1.2617E+27
80 - 90N	1.7148E+24	2.9941E+23	2.2675E+24	2.6099E+23	2.4993E+23	1.1496E+27	1.0957E+27

Figure 2.3.4-19

CASE 88-SUP2.4/SUB0.9
YEAR 2015 SUB/SUPERSONIC MIX

26,000 FT ALTITUDE	TOTAL CO MOLECULES/SEC	TOTAL HC (CH4) MOLECULES/SEC	TOTAL NO MOLECULES/SEC	TOTAL NO2 MOLECULES/SEC	TOTAL SO2 MOLECULES/SEC	TOTAL CO2 MOLECULES/SEC	TOTAL H2O MOLECULES/SEC
80 - 90S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
70 - 80S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
60 - 70S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
50 - 60S	1.2447E+21	8.1418E+20	5.1122E+21	5.8842E+20	2.3605E+20	9.8705E+23	9.4082E+23
40 - 50S	2.3846E+22	7.2227E+21	2.1022E+23	2.4196E+22	9.6207E+21	4.0229E+25	3.8345E+25
30 - 40S	1.6680E+23	5.2428E+22	1.5461E+24	1.7796E+23	6.9124E+22	2.8904E+26	2.7550E+26
20 - 30S	2.1153E+23	6.6748E+22	2.2029E+24	2.5356E+23	9.3883E+22	3.9257E+26	3.7418E+26
10 - 20S	5.0024E+22	1.4511E+22	4.5245E+23	5.2077E+22	2.0313E+22	8.4938E+25	8.0960E+25
0 - 10S	1.3207E+23	4.4095E+22	1.3007E+24	1.4971E+23	5.7072E+22	2.3865E+26	2.2747E+26
0 - 10N	1.8488E+23	6.7905E+22	2.0245E+24	2.3302E+23	8.7185E+22	3.6456E+26	3.4749E+26
10 - 20N	3.4285E+23	1.3299E+23	3.5689E+24	4.1078E+23	1.5480E+23	6.4729E+26	6.1697E+26
20 - 30N	7.6441E+23	2.5743E+23	7.2154E+24	8.3050E+23	3.1794E+23	1.3295E+27	1.2672E+27
30 - 40N	5.8893E+24	2.0960E+24	5.4903E+25	6.3193E+24	2.4040E+24	1.0052E+28	9.5813E+27
40 - 50N	3.6663E+24	1.3451E+24	3.4199E+25	3.9363E+24	1.4951E+24	6.2517E+27	5.9590E+27
50 - 60N	1.2638E+24	4.4976E+23	1.3032E+25	1.5000E+24	5.5896E+23	2.3373E+27	2.2278E+27
60 - 70N	1.8072E+23	6.8807E+22	1.7194E+24	1.9790E+23	7.4598E+22	3.1193E+26	2.9732E+26
70 - 80N	3.3637E+20	3.0911E+19	1.0394E+21	1.1964E+20	8.5149E+19	3.5605E+23	3.3937E+23
80 - 90N	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

37,000 FT. ALTITUDE	TOTAL CO MOLECULES/SEC	TOTAL HC (CH4) MOLECULES/SEC	TOTAL NO MOLECULES/SEC	TOTAL NO2 MOLECULES/SEC	TOTAL SO2 MOLECULES/SEC	TOTAL CO2 MOLECULES/SEC	TOTAL H2O MOLECULES/SEC
80 - 90S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
70 - 80S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
60 - 70S	1.4375E+21	4.8482E+20	1.5679E+22	1.8046E+21	6.6098E+20	2.7639E+24	2.6345E+24
50 - 60S	6.1003E+21	2.2227E+21	5.9689E+22	6.8702E+21	2.5604E+21	1.0706E+25	1.0205E+25
40 - 50S	1.3648E+23	4.8619E+22	1.4945E+24	1.7202E+23	6.3239E+22	2.6443E+26	2.5205E+26
30 - 40S	1.1271E+25	1.3397E+24	1.9769E+25	2.2754E+24	8.7388E+23	3.6376E+27	3.4688E+27
20 - 30S	2.9350E+25	2.6420E+24	1.5723E+25	1.8098E+24	7.6887E+23	3.1661E+27	3.0226E+27
10 - 20S	1.8971E+25	1.8277E+24	1.5547E+25	1.7895E+24	7.1478E+23	2.9580E+27	2.8225E+27
0 - 10S	3.8866E+25	3.4104E+24	1.6670E+25	1.9188E+24	8.3715E+23	3.4350E+27	3.2805E+27
0 - 10N	2.5405E+25	2.4801E+24	2.2542E+25	2.5946E+24	1.0096E+24	4.1805E+27	3.9887E+27
10 - 20N	4.3830E+25	4.2421E+24	3.5749E+25	4.1148E+24	1.6331E+24	6.7573E+27	6.4478E+27
20 - 30N	3.6205E+26	3.0887E+25	1.1477E+26	1.3210E+25	6.1606E+24	2.5144E+28	2.4026E+28
30 - 40N	4.5879E+26	4.4507E+25	3.3667E+26	3.8751E+25	1.6057E+25	6.6393E+28	6.3356E+28
40 - 50N	6.9725E+26	6.0900E+25	2.6000E+26	2.9926E+25	1.3681E+25	5.6027E+28	5.3518E+28
50 - 60N	1.8549E+26	1.7875E+25	1.4373E+26	1.6544E+25	6.7068E+24	2.7742E+28	2.6472E+28
60 - 70N	6.7205E+25	5.8366E+24	2.5213E+25	2.9020E+24	1.3184E+24	5.3991E+27	5.1573E+27
70 - 80N	1.5185E+24	1.9678E+23	3.3251E+24	3.8272E+23	1.4424E+23	6.0101E+26	5.7307E+26
80 - 90N	6.8304E+22	2.3178E+22	7.5384E+23	8.6767E+22	3.1687E+22	1.3250E+26	1.2629E+26

Figure 2.3.4-20

CASE B8-SUP2.4/SUB0.9
58,500 FT. ALTITUDE

	TOTAL CO MOLECULES/SEC	TOTAL HC (CH4) MOLECULES/SEC	TOTAL NO MOLECULES/SEC	TOTAL NO2 MOLECULES/SEC	TOTAL SO2 MOLECULES/SEC	TOTAL CO2 MOLECULES/SEC	TOTAL H2O MOLECULES/SEC
80 - 90S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
70 - 80S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
60 - 70S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
50 - 60S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
40 - 50S	1.2923E+22	3.2235E+20	1.3183E+22	1.5173E+21	9.6867E+20	3.7047E+24	3.5649E+24
30 - 40S	9.9867E+24	2.4910E+23	1.0187E+25	1.1726E+24	7.4857E+23	2.8629E+27	2.7549E+27
20 - 30S	6.6660E+24	1.6627E+23	6.8000E+24	7.8268E+23	4.9966E+23	1.9110E+27	1.8388E+27
10 - 20S	7.9843E+24	1.9916E+23	8.1448E+24	9.3746E+23	5.9848E+23	2.2889E+27	2.2025E+27
0 - 10S	7.8348E+24	1.9543E+23	7.9923E+24	9.1991E+23	5.8727E+23	2.2460E+27	2.1613E+27
0 - 10N	3.1981E+25	7.9773E+23	3.2624E+25	3.7550E+24	2.3972E+24	9.1682E+27	8.8222E+27
10 - 20N	3.0663E+25	7.6485E+23	3.1279E+25	3.6003E+24	2.2984E+24	8.7903E+27	8.4585E+27
20 - 30N	3.0187E+25	7.5298E+23	3.0794E+25	3.5444E+24	2.2627E+24	8.6539E+27	8.3273E+27
30 - 40N	5.6328E+25	1.4050E+24	5.7460E+25	6.6136E+24	4.2221E+24	1.6148E+28	1.5538E+28
40 - 50N	1.0998E+26	2.7433E+24	1.1219E+26	1.2913E+25	8.2438E+24	3.1529E+28	3.0339E+28
50 - 60N	4.9604E+25	1.2373E+24	5.0600E+25	5.8241E+24	3.7181E+24	1.4220E+28	1.3683E+28
60 - 70N	4.8469E+24	1.2090E+23	4.9443E+24	5.6909E+23	3.6331E+23	1.3895E+27	1.3370E+27
70 - 80N	5.2092E+24	1.2994E+23	5.3139E+24	6.1163E+23	3.9046E+23	1.4933E+27	1.4370E+27
80 - 90N	4.5241E+24	1.1285E+23	4.6150E+24	5.3119E+23	3.3911E+23	1.2969E+27	1.2480E+27

Figure 2.3.4-21

CASE B9-SUP2.1/SUB0.9
YEAR 2015 SUB/SUPERSONIC MIX

26,000 FT ALTITUDE

	TOTAL CO MOLECULES/SEC	TOTAL HC (CH4) MOLECULES/SEC	TOTAL NO MOLECULES/SEC	TOTAL NO2 MOLECULES/SEC	TOTAL SO2 MOLECULES/SEC	TOTAL CO2 MOLECULES/SEC	TOTAL H2O MOLECULES/SEC
80 - 90S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
70 - 80S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
60 - 70S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
50 - 60S	1.2447E+21	8.1418E+20	5.1122E+21	5.8842E+20	2.3605E+20	9.8705E+23	9.4082E+23
40 - 50S	2.3846E+22	7.2227E+21	2.1022E+23	2.4196E+22	9.6207E+21	4.0229E+25	3.8345E+25
30 - 40S	1.6680E+23	5.2428E+22	1.5461E+24	1.7796E+23	6.9124E+22	2.8904E+26	2.7550E+26
20 - 30S	2.1153E+23	6.6748E+22	2.2029E+24	2.5356E+23	9.3883E+22	3.9257E+26	3.7418E+26
10 - 20S	5.0024E+22	1.4511E+22	4.5245E+23	5.2077E+22	2.0313E+22	8.4938E+25	8.0960E+25
0 - 10S	1.3207E+23	4.4095E+22	1.3007E+24	1.4971E+23	5.7072E+22	2.3865E+26	2.2747E+26
0 - 10N	1.8488E+23	6.7905E+22	2.0245E+24	2.3302E+23	8.7185E+22	3.6456E+26	3.4749E+26
10 - 20N	3.4285E+23	1.3299E+23	3.5689E+24	4.1078E+23	1.5480E+23	6.4729E+26	6.1697E+26
20 - 30N	7.6441E+23	2.5743E+23	7.2154E+24	8.3050E+23	3.1794E+23	1.3295E+27	1.2672E+27
30 - 40N	5.8893E+24	2.0960E+24	5.4903E+25	6.3193E+24	2.4040E+24	1.0052E+28	9.5813E+27
40 - 50N	3.6663E+24	1.3451E+24	3.4199E+25	3.9363E+24	1.4951E+24	6.2517E+27	5.9590E+27
50 - 60N	1.2638E+24	4.4976E+23	1.3032E+25	1.5000E+24	5.5896E+23	2.3373E+27	2.2278E+27
60 - 70N	1.8072E+23	6.8807E+22	1.7194E+24	1.9790E+23	7.4598E+22	3.1193E+26	2.9732E+26
70 - 80N	3.3637E+20	3.0911E+19	1.0394E+21	1.1964E+20	8.5149E+19	3.5605E+23	3.3937E+23
80 - 90N	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

37,000 FT. ALTITUDE

	TOTAL CO MOLECULES/SEC	TOTAL HC (CH4) MOLECULES/SEC	TOTAL NO MOLECULES/SEC	TOTAL NO2 MOLECULES/SEC	TOTAL SO2 MOLECULES/SEC	TOTAL CO2 MOLECULES/SEC	TOTAL H2O MOLECULES/SEC
80 - 90S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
70 - 80S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
60 - 70S	1.4375E+21	4.8482E+20	1.5679E+22	1.8046E+21	6.6098E+20	2.7639E+24	2.6345E+24
50 - 60S	6.1003E+21	2.2227E+21	5.9689E+22	6.8702E+21	2.5604E+21	1.0706E+25	1.0205E+25
40 - 50S	1.3648E+23	4.8619E+22	1.4945E+24	1.7202E+23	6.3239E+22	2.6443E+26	2.5205E+26
30 - 40S	3.3709E+24	8.7153E+23	1.9652E+25	2.2619E+24	8.6168E+23	3.6174E+27	3.4480E+27
20 - 30S	6.0061E+24	1.2588E+24	1.5376E+25	1.7698E+24	7.3282E+23	3.1065E+27	2.9611E+27
10 - 20S	4.2700E+24	9.5654E+23	1.5329E+25	1.7644E+24	6.9207E+23	2.9205E+27	2.7837E+27
0 - 10S	7.6000E+24	1.5578E+24	1.6206E+25	1.8653E+24	7.8887E+23	-3.3552E+27	3.1981E+27
0 - 10N	5.7876E+24	1.3177E+24	2.2250E+25	2.5610E+24	9.7930E+23	4.1305E+27	3.9370E+27
10 - 20N	9.7610E+24	2.2233E+24	3.5243E+25	4.0565E+24	1.5805E+24	6.6704E+27	6.3580E+27
20 - 30N	6.7867E+25	1.3455E+25	1.1040E+26	1.2707E+25	5.7063E+24	2.4393E+28	2.3251E+28
30 - 40N	1.0223E+26	2.3379E+25	3.3137E+26	3.8141E+25	1.5506E+25	6.5484E+28	6.2417E+28
40 - 50N	1.3460E+26	2.7560E+25	2.5163E+26	2.8963E+25	1.2812E+25	5.4592E+28	5.2036E+28
50 - 60N	4.1168E+25	9.3224E+24	1.4159E+26	1.6297E+25	6.4839E+24	2.7374E+28	2.6092E+28
60 - 70N	1.2916E+25	2.6197E+24	2.4406E+25	2.8091E+24	1.2346E+24	5.2607E+27	5.0143E+27
70 - 80N	4.9835E+23	1.3632E+23	3.3099E+24	3.8097E+23	1.4267E+23	5.9841E+26	5.7038E+26
80 - 90N	6.8304E+22	2.3178E+22	7.5384E+23	8.6767E+22	3.1687E+22	1.3250E+26	1.2629E+26

Figure 2.3.4-22

CASE B9-SUP2.1/SUB0.9
56,700 FT. ALTITUDE

	TOTAL CO MOLECULES/SEC	TOTAL HC (CH4) MOLECULES/SEC	TOTAL NO MOLECULES/SEC	TOTAL NO2 MOLECULES/SEC	TOTAL SO2 MOLECULES/SEC	TOTAL CO2 MOLECULES/SEC	TOTAL H2O MOLECULES/SEC
80 - 90S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
70 - 80S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
60 - 70S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
50 - 60S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
40 - 50S	5.0978E+21	8.9009E+20	6.7410E+21	7.7589E+20	7.4299E+20	3.4175E+24	3.2574E+24
30 - 40S	3.9395E+24	6.8785E+23	5.2093E+24	5.9960E+23	5.7417E+23	2.6410E+27	2.5173E+27
20 - 30S	2.6296E+24	4.5913E+23	3.4772E+24	4.0022E+23	3.8325E+23	1.7628E+27	1.6803E+27
10 - 20S	3.1496E+24	5.4993E+23	4.1648E+24	4.7937E+23	4.5905E+23	2.1115E+27	2.0126E+27
0 - 10S	3.0906E+24	5.3964E+23	4.0869E+24	4.7040E+23	4.5045E+23	2.0719E+27	1.9749E+27
0 - 10N	1.2616E+25	2.2028E+24	1.6682E+25	1.9201E+24	1.8387E+24	8.4575E+27	8.0614E+27
10 - 20N	1.2096E+25	2.1120E+24	1.5995E+25	1.8410E+24	1.7629E+24	8.1089E+27	7.7291E+27
20 - 30N	1.1908E+25	2.0792E+24	1.5747E+25	1.8124E+24	1.7356E+24	7.9831E+27	7.6092E+27
30 - 40N	2.2220E+25	3.8796E+24	2.9382E+25	3.3819E+24	3.2385E+24	1.4896E+28	1.4198E+28
40 - 50N	4.3384E+25	7.5751E+24	5.7369E+25	6.6032E+24	6.3232E+24	2.9084E+28	2.7722E+28
50 - 60N	1.9567E+25	3.4165E+24	2.5875E+25	2.9782E+24	2.8519E+24	1.3118E+28	1.2503E+28
60 - 70N	1.9120E+24	3.3384E+23	2.5283E+24	2.9101E+23	2.7867E+23	1.2818E+27	1.2217E+27
70 - 80N	2.0549E+24	3.5879E+23	2.7173E+24	3.1276E+23	2.9950E+23	1.3776E+27	1.3131E+27
80 - 90N	1.7846E+24	3.1160E+23	2.3599E+24	2.7162E+23	2.6011E+23	1.1964E+27	1.1404E+27

Figure 2.3.4-23

CASE B10-SUP2.4/SUP1.5
YEAR 2015 SUB/SUPERSONIC MIX

26,000 FT ALTITUDE

	TOTAL CO MOLECULES/SEC	TOTAL HC (CH4) MOLECULES/SEC	TOTAL NO MOLECULES/SEC	TOTAL NO2 MOLECULES/SEC	TOTAL SO2 MOLECULES/SEC	TOTAL CO2 MOLECULES/SEC	TOTAL H2O MOLECULES/SEC
80 - 90S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
70 - 80S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
60 - 70S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
50 - 60S	1.2447E+21	8.1418E+20	5.1122E+21	5.8842E+20	2.3605E+20	9.8705E+23	9.4082E+23
40 - 50S	2.3846E+22	7.2227E+21	2.1022E+23	2.4196E+22	9.6207E+21	4.0229E+25	3.8345E+25
30 - 40S	1.6680E+23	5.2428E+22	1.5461E+24	1.7796E+23	6.9124E+22	2.8904E+26	2.7550E+26
20 - 30S	2.1153E+23	6.6748E+22	2.2029E+24	2.5356E+23	9.3883E+22	3.9257E+26	3.7418E+26
10 - 20S	5.0024E+22	1.4511E+22	4.5245E+23	5.2077E+22	2.0313E+22	8.4938E+25	8.0960E+25
0 - 10S	1.3207E+23	4.4095E+22	1.3007E+24	1.4971E+23	5.7072E+22	2.3865E+26	2.2747E+26
0 - 10N	1.8488E+23	6.7905E+22	2.0245E+24	2.3302E+23	8.7185E+22	3.6456E+26	3.4749E+26
10 - 20N	3.4285E+23	1.3299E+23	3.5689E+24	4.1078E+23	1.5480E+23	6.4729E+26	6.1697E+26
20 - 30N	7.6441E+23	2.5743E+23	7.2154E+24	8.3050E+23	3.1794E+23	1.3295E+27	1.2672E+27
30 - 40N	5.8893E+24	2.0960E+24	5.4903E+25	6.3193E+24	2.4040E+24	1.0052E+28	9.5813E+27
40 - 50N	3.6663E+24	1.3451E+24	3.4199E+25	3.9363E+24	1.4951E+24	6.2517E+27	5.9590E+27
50 - 60N	1.2638E+24	4.4976E+23	1.3032E+25	1.5000E+24	5.5896E+23	2.3373E+27	2.2278E+27
60 - 70N	1.8072E+23	6.8807E+22	1.7194E+24	1.9790E+23	7.4598E+22	3.1193E+26	2.9732E+26
70 - 80N	3.3637E+20	3.0911E+19	1.0394E+21	1.1964E+20	8.5149E+19	3.5605E+23	3.3937E+23
80 - 90N	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

37,000 FT. ALTITUDE

	TOTAL CO MOLECULES/SEC	TOTAL HC (CH4) MOLECULES/SEC	TOTAL NO MOLECULES/SEC	TOTAL NO2 MOLECULES/SEC	TOTAL SO2 MOLECULES/SEC	TOTAL CO2 MOLECULES/SEC	TOTAL H2O MOLECULES/SEC
80 - 90S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
70 - 80S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
60 - 70S	1.4375E+21	4.8482E+20	1.5679E+22	1.8046E+21	6.6098E+20	2.7639E+24	2.6345E+24
50 - 60S	6.1003E+21	2.2227E+21	5.9689E+22	6.8702E+21	2.5604E+21	1.0706E+25	1.0205E+25
40 - 50S	1.3648E+23	4.8619E+22	1.4945E+24	1.7202E+23	6.3239E+22	2.6443E+26	2.5205E+26
30 - 40S	1.8060E+24	5.9829E+23	1.9559E+25	2.2512E+24	8.2747E+23	3.4600E+27	3.2980E+27
20 - 30S	1.3821E+24	4.5141E+23	1.5101E+25	1.7382E+24	6.3173E+23	2.6416E+27	2.5178E+27
10 - 20S	1.3580E+24	4.4808E+23	1.5156E+25	1.7444E+24	6.2841E+23	2.6277E+27	2.5046E+27
0 - 10S	1.4066E+24	4.7637E+23	1.5837E+25	1.8229E+24	6.5347E+23	2.7325E+27	2.6045E+27
0 - 10N	1.9018E+24	6.3919E+23	2.2019E+25	2.5344E+24	8.9435E+23	3.7397E+27	3.5646E+27
10 - 20N	3.0123E+24	1.0450E+24	3.4841E+25	4.0103E+24	1.4329E+24	5.9917E+27	5.7111E+27
20 - 30N	9.5930E+24	3.2803E+24	1.0693E+26	1.2308E+25	4.4323E+24	1.8533E+28	1.7665E+28
30 - 40N	3.1603E+25	1.1047E+25	3.2717E+26	3.7657E+25	1.3962E+25	5.8381E+28	5.5647E+28
40 - 50N	2.3143E+25	8.0998E+24	2.4500E+26	2.8200E+25	1.0375E+25	4.3385E+28	4.1353E+28
50 - 60N	1.2579E+25	4.3306E+24	1.3989E+26	1.6101E+25	5.8589E+24	2.4499E+28	2.3351E+28
60 - 70N	2.1617E+24	7.4197E+23	2.3766E+25	2.7355E+24	9.9947E+23	4.1793E+27	3.9835E+27
70 - 80N	2.9627E+23	1.0104E+23	3.2979E+24	3.7959E+23	1.3825E+23	5.7808E+26	5.5101E+26
80 - 90N	6.8304E+22	2.3178E+22	7.5384E+23	8.6767E+22	3.1687E+22	1.3250E+26	1.2629E+26

Figure 2.3.4-24

CASE B10-SUP2.4/SUP1.5
46,000 FT. ALTITUDE

	TOTAL CO MOLECULES/SEC	TOTAL HC (CH4) MOLECULES/SEC	TOTAL NO MOLECULES/SEC	TOTAL NO2 MOLECULES/SEC	TOTAL SO2 MOLECULES/SEC	TOTAL CO2 MOLECULES/SEC	TOTAL H2O MOLECULES/SEC
80 - 90S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
70 - 80S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
60 - 70S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
50 - 60S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
40 - 50S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
30 - 40S	2.6522E+23	4.6309E+22	2.0341E+23	2.3413E+22	3.8656E+22	1.7780E+26	1.6948E+26
20 - 30S	7.7877E+23	1.3598E+23	5.9729E+23	6.8748E+22	1.1351E+23	5.2208E+26	4.9763E+26
10 - 20S	4.9045E+23	8.5634E+22	3.7615E+23	4.3295E+22	7.1482E+22	3.2879E+26	3.1339E+26
0 - 10S	1.0431E+24	1.8213E+23	8.0000E+23	9.2080E+22	1.5203E+23	6.9927E+26	6.6652E+26
0 - 10N	6.5445E+23	1.1427E+23	5.0194E+23	5.7773E+22	9.5385E+22	4.3874E+26	4.1819E+26
10 - 20N	1.1366E+24	1.9846E+23	8.7173E+23	1.0034E+23	1.6566E+23	7.6197E+26	7.2629E+26
20 - 30N	9.8144E+24	1.7136E+24	7.5272E+24	8.6638E+23	1.4304E+24	6.5795E+27	6.2713E+27
30 - 40N	1.1895E+25	2.0770E+24	9.1233E+24	1.0501E+24	1.7337E+24	7.9745E+27	7.6011E+27
40 - 50N	1.8771E+25	3.2775E+24	1.4397E+25	1.6571E+24	2.7359E+24	1.2584E+28	1.1995E+28
50 - 60N	4.8149E+24	8.4071E+23	3.6928E+24	4.2505E+23	7.0177E+23	3.2279E+27	3.0767E+27
60 - 70N	1.8112E+24	3.1624E+23	1.3891E+24	1.5988E+23	2.6398E+23	1.2142E+27	1.1573E+27
70 - 80N	3.4035E+22	5.9426E+21	2.6103E+22	3.0045E+21	4.9605E+21	2.2816E+25	2.1748E+25
80 - 90N	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

Figure 2.3.4-25

CASE B10-SUP2.4/SUP1.5
60,000 FT. ALTITUDE

	TOTAL CO MOLECULES/SEC	TOTAL HC (CH4) MOLECULES/SEC	TOTAL NO MOLECULES/SEC	TOTAL NO2 MOLECULES/SEC	TOTAL SO2 MOLECULES/SEC	TOTAL CO2 MOLECULES/SEC	TOTAL H2O MOLECULES/SEC
80 - 90S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
70 - 80S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
60 - 70S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
50 - 60S	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
40 - 50S	4.8983E+21	8.5527E+20	6.4773E+21	7.4554E+20	7.1393E+20	3.2838E+24	3.1300E+24
30 - 40S	3.7853E+24	6.6093E+23	5.0055E+24	5.7613E+23	5.5171E+23	2.5376E+27	2.4188E+27
20 - 30S	2.5267E+24	4.4117E+23	3.3411E+24	3.8456E+23	3.6826E+23	1.6938E+27	1.6145E+27
10 - 20S	3.0264E+24	5.2841E+23	4.0019E+24	4.6062E+23	4.4109E+23	2.0288E+27	1.9338E+27
0 - 10S	2.9697E+24	5.1852E+23	3.9269E+24	4.5199E+23	4.3283E+23	1.9908E+27	1.8976E+27
0 - 10N	1.2122E+25	2.1166E+24	1.6030E+25	1.8450E+24	1.7668E+24	8.1265E+27	7.7459E+27
10 - 20N	1.1622E+25	2.0293E+24	1.5369E+25	1.7690E+24	1.6940E+24	7.7916E+27	7.4267E+27
20 - 30N	1.1442E+25	1.9978E+24	1.5130E+25	1.7415E+24	1.6677E+24	7.6707E+27	7.3114E+27
30 - 40N	2.1350E+25	3.7278E+24	2.8232E+25	3.2495E+24	3.1118E+24	1.4313E+28	1.3643E+28
40 - 50N	4.1687E+25	7.2787E+24	5.5124E+25	6.3448E+24	6.0758E+24	2.7946E+28	2.6638E+28
50 - 60N	1.8802E+25	3.2828E+24	2.4862E+25	2.8616E+24	2.7403E+24	1.2604E+28	1.2014E+28
60 - 70N	1.8372E+24	3.2078E+23	2.4294E+24	2.7962E+23	2.6776E+23	1.2316E+27	1.1739E+27
70 - 80N	1.9745E+24	3.4475E+23	2.6109E+24	3.0052E+23	2.8779E+23	1.3237E+27	1.2617E+27
80 - 90N	1.7148E+24	2.9941E+23	2.2675E+24	2.6099E+23	2.4993E+23	1.1496E+27	1.0957E+27

Figure 2.3.4-26

3.0 NOISE

This section will cover two issues: sonic booms and community noise at airports. Both are major environmental concerns that need to be addressed before an HSCT can be introduced. Each area will have a section on methodology of calculation, how to reduce the noise, criteria for acceptability and results.

3.1 SONIC BOOMS

3.1.1 Summary.

Sonic boom wave form parameters as related to loudness were investigated analytically. The parameters studied include rise time, duration, maximum overpressure and initial overpressure. A design goal of achieving noise levels equal to or less than 72 dBA for corridors and 65 dBA for unconstrained flight was chosen based on a review of published human response test results. The 72 dBA noise level can possibly be achieved with 1.0 psf shock waves. Airplane configuration studies have indicated that it may be possible to design an aircraft with such a sonic boom.

3.1.2 Introduction.

The sonic boom disturbance produced by a conventional HSCT would be too annoying for routine supersonic overland flight. Large supersonic aircraft typically produce sonic booms that have maximum overpressures of 2 to 3 psf. Commercial, overland, supersonic flights are not allowed by U. S. law. Thus, there is impetus to explore low-boom designs that would allow some form of overland supersonic operation, either in limited corridors (low population densities), or less likely, without any constraints. Such an eventuality would have a significant positive effect on the econimic success of an HSCT program.

The design of a low impact sonic boom aircraft is complicated by the lack of knowledge of what types of sonic boom pressure signatures are acceptable. To aid in analyzing the loudness of potential sonic boom wave forms and to develop acceptability criteria from human response test data, an analytical procedure for calculating sonic boom loudness was used.

This section describes low sonic boom airplane design methods, the sonic boom loudness calculation method, the effects of overpressure, rise time, duration, and a possible loudness criteria. The details of a particular configuration designed for reduced sonic boom impact can be found in the "Configuration Development" document, Sections 6.5, and 8.10.

3.1.3 Symbols and Abbreviations.

CHABA	=	Committee on Hearing, Bioacoustics and Biomechanics Assembly
D	=	Duration (ms)
dB	=	decibel
dBA	=	A-weighted decibel
Hz	=	Hertz
L_{CDN}	=	Day - Night Cumulative Noise, C weighted Scale
L_{DN}	=	Day - Night Cumulative Noise, A weighted Scale
M	=	Mach
ms	=	millisecond
P_{max}	=	Maximum overpressure (psf)
psf	=	pounds per square foot
P_{sh}	=	Initial shock overpressure (psf)
RT	=	Rise time (ms)
T	=	Time (seconds)

3.1.4 Study Results.

The following four areas will be discussed on the subject of sonic booms:
1. Methodology of low sonic boom airplane design,
2. Methodology of sonic boom loudness calculations,
3. Reduction of noise, what parameters are most sensitive to noise, and
4. Criteria for acceptability.

Method for Low Sonic Boom Airplane Design.
The basic theoretical methods used for calculating the sonic boom disturbance from a supersonic aircraft have been summarized by many investigators (References 1 through 4, for example). Sonic boom generation theory rests on linear supersonic aerodynamic analysis methods (with a non-linear correction) and on the concepts of the Whitham F-function and supersonic area rule. Sonic boom propagation is calculated using the linear theory of geometric acoustics (Reference 1). These methods have been verified by wind tunnel and flight test experimental data.

An inverse design process is used, where the desired pressure signature as observed on the ground is specified and then the airplane area distribution is determined for a given flight condition. The effect of propagation from the airplane to the ground is included. The airplane configuration is specified as a general equivalent area distribution, which must be separated into the volume and lifting elements to derive an airplane configuration. This method has been formulated into a computer program called "SEEB" (Reference 5). Figure 3.1.4-1 illustrates this design process. Further details are given in Reference 6 and also in the "Configuration Development" document, Section 6.5 and 8.10, where this method is applied to a particular configuration.

Typical sonic boom pressure signatures for conventional configurations, the U.S. SST design (B2707-300) and the 1080-808, are shown in Figure 3.1.4-2. The calculated overpressure levels are shown in Figure 3.1.4-3 for the climb, cruise, and descent legs (Configuration 1080-808). The potential for sonic boom reduction is shown in Figure 3.1.4-4, where low boom pressure signatures (both minimum overpressure and minimum shock) are compared to the 1080-808 for a M 2.4 start-of-cruise condition.

The applications of this low sonic boom design method (as used in "Configuration Development," Section 6.5 and 8.10) has shown that it is certainly adequate for preliminary design studies for the Mach range from 1.3 to 3.0. The method needs to be extended, however, to facilitate the conversion of the total equivalent area distribution into volumetric shapes and lifting surfaces. This is a difficult problem if done by hand, due to the large amount of data involved, the fact that there is no direct unique solution, and also because iterations are required.

The current methods neglect several non-linear and secondary effects, such as boundary layer and exhaust plume growth. These effects, should be evaluated and included, if necessary, before low sonic boom designs proceed to the advanced design stage. In addition, the basic calculations need to be done with somewhat better defined geometry and accuracy than is necessary for conventional configurations. This is because the approach used for sonic boom reduction is to design aircraft to produce "near-field" or "mid-field" wave forms at the ground. By definition, these wave forms have not developed into the classical N-wave form, so that the details of the airplane volume and lift distributions are important. Therefore, the geometry definitions, inverse design methods, and analysis methods must all have the same level of accuracy. Some of the methods developed in the past are simplified and have been widely used because of the quick, simple estimates they provide (for example, the simplified sonic boom prediction method of Carlson in Reference 7). The simplified methods, however, assume N-wave forms and therefore are not valid for low boom mid-field waveforms.

Method for Sonic Boom Loudness Calculation.

In order to analyze sonic booms in terms of noise level, the pressure-time wave form must be converted to a frequency spectrum. To obtain a frequency spectrum a Fourier transform is performed on the wave shape. The sound pressure level is determined relative to the reference pressure (re = 0.00005 N/m^2). A Butterworth filter is then used to convert to 1/3 octave bandwidth. The method used is outlined by Johnson and Robinson (Reference 8).

The frequency spectrum for an N-wave of overpressure equal to 1.0 psf is shown in Figure 3.1.4-5 (from Reference 8). From this it can be seen that both rise time and duration will effect the spectrum. As either rise time or duration increase, frequencies f1 and f2 will shift to lower values, thereby reducing the high frequency content. The audible range is between 20 Hz and 20000 Hz, so any reduction in this region will reduce the loudness of the boom. The Fletcher-Munson contours or phon contours can be used to define loudness. These contours were originally determined by psychoacoustic experiments. Each observer was asked to judge two sounds at different frequencies for equal loudness; thus, the equal loudness contours were formed. The Fletcher-Munson contours were used to determine the dBA weighting factor for each frequency.

The peak sound pressure level of a sonic boom is usually between 2 and 6 Hz. Because of such low frequencies, consideration of infrasound response is needed. Infrasound is the region below 20 Hz. A study conducted in Paris (Reference 9) proposed a criteria for infrasound based on the threshold of hearing and the threshold of aural pain for low frequencies (Figure 3.1.4-6). There is also some concern with such low frequencies as they are transmitted through walls. It is known that these low frequencies will cause buildings, windows, bric-a-brac, etc., to rattle, but not much else is known. There is no data nor has a theoretical analysis been done to determine what happens to the shock wave as it is transmitted through walls.

One parameter that has a big impact on the loudness is rise time. Unfortunately, current linear propagation procedures do not accurately predict the rise times. Data indicates that rise time can vary between 5 and 15 ms, depending on the airplane cruise altitude (Reference 10). It is believed that atmospheric absorption (also called molecular relaxation) is a major contributor to the finite rise times. Atmospheric absorption is currently not included in the prediction of wave propagation.

A quick and simple estimate of the effect of atmospheric absorption was made. A Fourier transform was performed on a wave (1 psf, RT = 0) to obtain the frequency spectrum. This spectrum was then corrected for atmospheric absorption for cruise altitude to ground. The result was then compared to spectra of the same wave shape (1 psf N-wave) but modified to simulate measured wave forms with linear and nonlinear rise times (RT = 1 - 10 ms). The atmospheric absorption result, as shown in Figure 3.1.4-7 (RT=3ms) is a spectrum that is much different then real spectra. It can therefore be concluded that this simple method of including atmospheric absorption is not valid. A nonlinear propagation theory is needed that would include atmospheric absorption and turbulence effects. A better understanding of the atmosphere at the different altitudes is needed (i.e., humidity profile and temperature profile). The sensitivity of the sonic boom to changes in the atmosphere must also be understood. It has been observed that the same airplane flying over the same location at different times can have two completely different sounding sonic booms. Once a prediction method has been developed and verified, a statistical analysis needs to be done to determine the probability that the sonic boom loudness will be below a certain level.

Reduction of Noise.

The most common wave shape associated with sonic boom overpressure is the N-wave (Figure 3.1.4-8). Another wave shape, studied by Niedzwiecki (Reference 11), called the minimum shock low boom wave form is also shown in Figure 3.1.4-8. Niedzwiecki reported the results of human response testing, and determined the equivalent loudness of the N-wave and the minimum shock low boom wave. The two wave forms shown in Figure 3.1.4-8 (from Reference 11) were rated to be of equal loudness.

The parameters that effect the noise include: initial shock intensity, maximum overpressure, shock wave rise time and duration. All four parameters were varied to determine their sensitivity.

For N-waves, the two parameters that have the most effect on loudness are rise time and maximum overpressure. Any reduction in the maximum overpressure will reduce the loudness, but for a large commercial transport it is unrealistic to anticipate levels below 2.0 psf. Duration also effects loudness, but very little benefit is achieved by airplane configuration modifications and there is a big penalty to the aircraft.

For the minimum shock low boom, one would expect that by reducing the maximum overpressure the loudness would be reduced, this however is not the case (Figure 3.1.4-9). Change in the maximum overpressure has very little effect on loudness, but it will affect the peak noise level (infrasound). Reduction of the initial shock (sometimes referred to as the front shock) will reduce the loudness (Figure 3.1.4-10).

Criteria for Acceptability.

Within the statement of work for Task 7 of the HSCT contract there is a requirment to define a criteria for sonic booms. Two elements will be discussed: (1) what noise that is acceptable, and (2) how should sonic booms be measured so that a rule can be defined.

Development of acceptability critera for sonic boom requires extensive human response testing that could not be conducted under the current contract. However, a literature search of published human response testing was done. The loudness calculation method described above was used to evaluate the tested waveforms for loudness in dBA, which was then related to the human response test results. These results are shown in Figure 3.1.4-11 (from Reference 6). From these results, the goals that were chosen are:

1. Noise levels must be equal to or less than 72 dBA for restricted overland flight (corridors),
2. Noise levels must be equal to or less than 65 dBA for unrestricted overland flight.

It was decided to use dBA because of its simplicity, and it was determined that the sensitivity was similar to other commonly used noise metrics for sonic booms (see Figure 3.1.4-12, from Reference 6). The concern with using dBA is that the low frequency content is ignored because of the large negative weighting factors at the low frequencies. A conference held in Paris (Reference 9) had determined a criteria for infrasound (Figure 3.1.4-6); it is recommened that this criterion also be used.

The criteria proposed is for a single event, which is required to make airplane design decisions. A cummulative event criteria may ultimately be useful. CHABA (Committee on Hearing, Bioacoustics and Biomechanics Assembly) proposed using L_{CDN} (Reference 12); it was intended to be used on a wide variety of impulsive sounds. Not enough is known at this time if L_{CDN} or if L_{DN} is the right one to use. The problem with L_{CDN} (or dBC for single event) is that it does not indicate loudness since hearing characteristics are not accounted for.

Currently there is no regulatory rule or recommended practice for measurement of sonic booms. Enough is known about sonic boom propagation to know that under quiescent, normal atmospheric conditions the peak noise level occurs directly under the flight path and then diminishes to the side. Wind velocity and non-uniform atmospheric conditions affect the way the boom travels laterally.

As far as the measurement technique is concerned, it is recommended that a system similar to that developed for the Air Force AAMRC, the Boom Event Analyzer Recorder (BEAR) illustrated in

Figure 3.1.4-13, be used. This is a 16 bit microprocessor that continuously samples the noise then captures and stores the digital waveform for any impulse noise. The sonic booms are stored on solid state random access memory that can be later retrieved and transferred to a microcomputer. Eight data points are obtained every millisecond. Up to 100 booms can be stored. The BEAR is designed to operate with a PCB Piezo resistive microphone that is totally sealed. In some situations it may not be necessary to have the detection and storage capability.

Measurements should be taken directly under the flight path because that is where the peak overpressure occurs. An array two miles to each side is recommended to insure measuring the peak. With the BEAR's system, the microphone is flush mounted on the ground; the boom levels are therefore multiplied by a factor of two by ground reflection. The analysis at Boeing for the propagation prediction multiplies by a factor of 1.9 for ground reflection to a typical FAR 36 microphone height. Not enough is known as to what other effects ground reflection has on sonic booms; therefore, no other recommendation can be made at this time.

3.1.5 Conclusions

The evaluation of the design methods for sonic boom reduction has shown the following:

1. Available methods are barely adequate for preliminary configuration development in the Mach range from 1.3 to about 3.0.
2. Low sonic boom airplane geometry definitions, analysis methods, and inverse design methods must have sufficient accuracy to reflect the configuration details more exactly than required for conventional configurations.
3. Methods need to be developed to facilitate the conversion of the total equivalent area distribution into volumetric shapes and lifting surfaces.

The analysis of sonic boom loudness has shown the following:

1. A review of published human response test results suggests criteria for maximum noise of 72 dBA for limited corridor and 65 dBA for unconstrained overland supersonic flight. A separate criterion was identified for infrasound.
2. The most significant wave form parameters in terms of loudness are: rise time, initial overpressure (minimum shock low boom) and maximum overpressure (N-waves). Duration has little effect on loudness. Maximum overpressure (minimum shock low boom) has most significant effect on infrasound.
3. Due to the short time duration of the sonic boom disturbance, an impulsive criterion is needed. A time-integrated metric such as Lc_{DN} might also prove useful, but no criterion was defined.
4. Considerable human response testing is needed to answer some basic unknowns:

-- Noise metric selection
-- Indoor versus outdoor response
-- Shock wave rise time effects
-- Atmospheric absorption effects
-- Criteria for acceptability

3.1.6 References

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3.2 COMMUNITY NOISE

3.2.1 Summary

The two main objectives of the noise impact study were to determine (1) if stage 3 noise rules can nominally be met and (2) can the community noise exposure be equal to or better than the selected 747-200 based on footprint area. An assessment of engine oversizing, wing loading and takeoff procedures was made to determine if these objectives could be met. It was found that with an 11.7% engine size increase Stage 3 could be met and this was a 4.7% increase in airplane TOGW. The equal area footprint objective was more prohibitive requiring 28% engine oversizing and causing a 12.1% TOGW penalty. Nominal FAR36 Stage 3 levels were achieved with the highest wing loading and using a special takeoff procedure (20% PLR). Airport and residential areas were assessed for noise exposure of 85 dBA or more . The footprint of the FAR36 Stage 3 version of the HSCT was very similar to the 747 footprint. It was found that the footprint without using the special takeoff procedure had the lowest airport environmental impact with 37% less residential area exposed. However, modification to FAR 36 would be required for the HSCT to be certifiable without using the special takeoff procedure.

3.2.2 Introduction

Nominally achieving the noise levels of the current subsonic noise rule, FAR36 Stage 3, was the original community noise goal in the HSCT contract. Indications from early studies were that meeting Stage 3 at the sideline measuring point would be extremely difficult but that achieving an 85 dBA footprint area of a Stage 3 airplane might be possible and hence an "equivalent" Stage 3 rule based upon "equal area" might be appropriate. This "equivalent" Stage 3 area was identified as that produced by a 747-200 (JT9D-7Q) which just meets Stage 3 rules. This was a second goal in the Task 5 study where impact to the HSCT to achieve these goals was assessed. In Task 7 the airport study assessed these various footprints at anticipated HSCT airports and residential community noise exposure was compared. This section examines the results of these two studies with respect to HSCT community noise rule and technology development implications.

3.2.3 Symbols and Abbreviations

20% PLR	Programmed Lapse Rate thrust reduction of 20%
85 dBA	A-weighted overall sound pressure level of 85 dB
EPNdB	Effective Perceived Noise level in decibels
FAR36	Federal Aviation Regulation, Section 36
Footprint	Noise exposure contour
L/D	Lift over Drag
NACA	Naturally Aspirated Co-Annular
P&W	Pratt & Whitney, engine manufacturer
PPS	Pounds Per Second
T/W	Thrust to Weight Ratio
TOGW	Takeoff Gross Weight

3.2.4 Community Noise Summary (Task 5)

The two main objectives of the noise impact study were to determine (1) if Stage 3 noise rules can nominally be met and (2) can the community noise exposure be equal to or better than a 747-200 based on footprint area.

A key element is the takeoff procedure. Several procedures were assessed resulting in identification of one (the 20% PLR procedure) that provided the lowest sideline noise. The 20% PLR takeoff procedure is a full power takeoff to 35 ft. altitude followed by a programmed lapse rate (PLR) to 80% power, to prevent sideline noise from increasing as the airplane climbs out of the ground attenuation and engine shielding region, and finally a normal cutback to the 4% climb gradient requirement of FAR36.

It was estimated that with the baseline double delta (high loading) wing and oversizing the engine by 11.7% (582 pps to 650 pps) Stage 3 can be met with a corresponding weight penalty to the airplane of 4.7% (Figure 3.2.4-1).

With a fixed engine size reduced wing loading was found to increase sideline noise for the derate takeoff procedure since the weight increase reduced the thrust to weight ratio, limiting derate, which more than offset the improvement in lift to drag.

With the high wing loading the engine oversizing required to meet the equal area criterion was 28% (582 pps to 745 pps) resulting in a 12.1% TOGW penalty (Figure 3.2.4-1). The best takeoff procedure for minimum footprint area was with the engine thrust derated to the takeoff field length requirement. This TOGW increase is prohibitive.

3.2.5 Airport Community Noise Environmental Study (Task 7)

The environmental impact of HSCT noise relative to the 747 was then assessed at 18 potential HSCT airports. This assessment was made with 85 dBA noise contours (footprints). Three footprints of HSCTs were compared to the 747 footprint. Characteristics of the HSCT configurations/takeoff procedures are as follows:

1. Engine sized to 650 pps and 20% PLR takeoff procedure (meets Stage 3)
2. Engine sized to 650 pps full power takeoff (to the FAR36 cutback point)
3. Minimum size engine (582 pps) full power takeoff (to the FAR36 cutback point)

To evaluate the environmental impact these footprints were overlayed on 18 potential HSCT airports. The residential area that was within the 85 dBA contour was measured and summed. The HSCT and 747 footprints were then tabulated. The 747-200 footprint and HSCT, 650 pps engine and 20% PLR takeoff, are almost identical as shown in Figure 3.2.5-1. The area of the HSCT footprint is somewhat larger but as shown (Figure 3.2.5-2) the increased area is along the runway, before lift off. Thus the increased area is generally on the airport property and would not increase community noise exposure at levels above 85 dBA. The footprint produced using full power takeoff is wider along the runway with higher sideline noise (6.6 EPNdB), but much shorter down range from the runway, such that residential noise exposure to levels over 85 dBA is reduced at nearly all of the airports studied and is nearly the same exposure with the minimum size engine (Tables 3.2.5-1 and 3.2.5-2). For maximum benefit to airport communities, noise regulations should take advantage of this characteristic of an HSCT airplane. This could be accomplished by increasing the maximum trade provision. This would not be an increase in total cummunity noise since significantly reduced down range community noise is being traded for somewhat increased airport sideline noise.

3.2.6 Conclusions.

The current HSCT contract goal of meeting FAR36 Stage 3 noise levels has been examined. With the currently estimated jet noise suppression levels for the NACA nozzle the Stage 3 sideline noise can be "nominally" met by increasing the engine size 11.7% with a 4.7% TOGW penalty. The 85 dBA footprint that is achieved with this takeoff procedure is very similar to the footprint of a 747-200 that is certified to Stage 3. A normal FAR36 takeoff procedure for this same configuration is 6.6 EPNdB above Stage 3 at the sideline measuring point, the footprint is wider (on the airport) but shorter (in the community) and actually reduces residential noise exposure by an average of 37%. A modification to the noise rule would be required for the HSCT to be certifiable with this procedure and take advantage of the HSCT's unique noise characteristics. The level of jet noise suppression achievable is the critical element and much developmental work is required in this area; i.e., another 2 EPNdB of suppression would mean no oversizing would be required while 2 EPNdB less suppression would mean Stage 3 is not achievable.

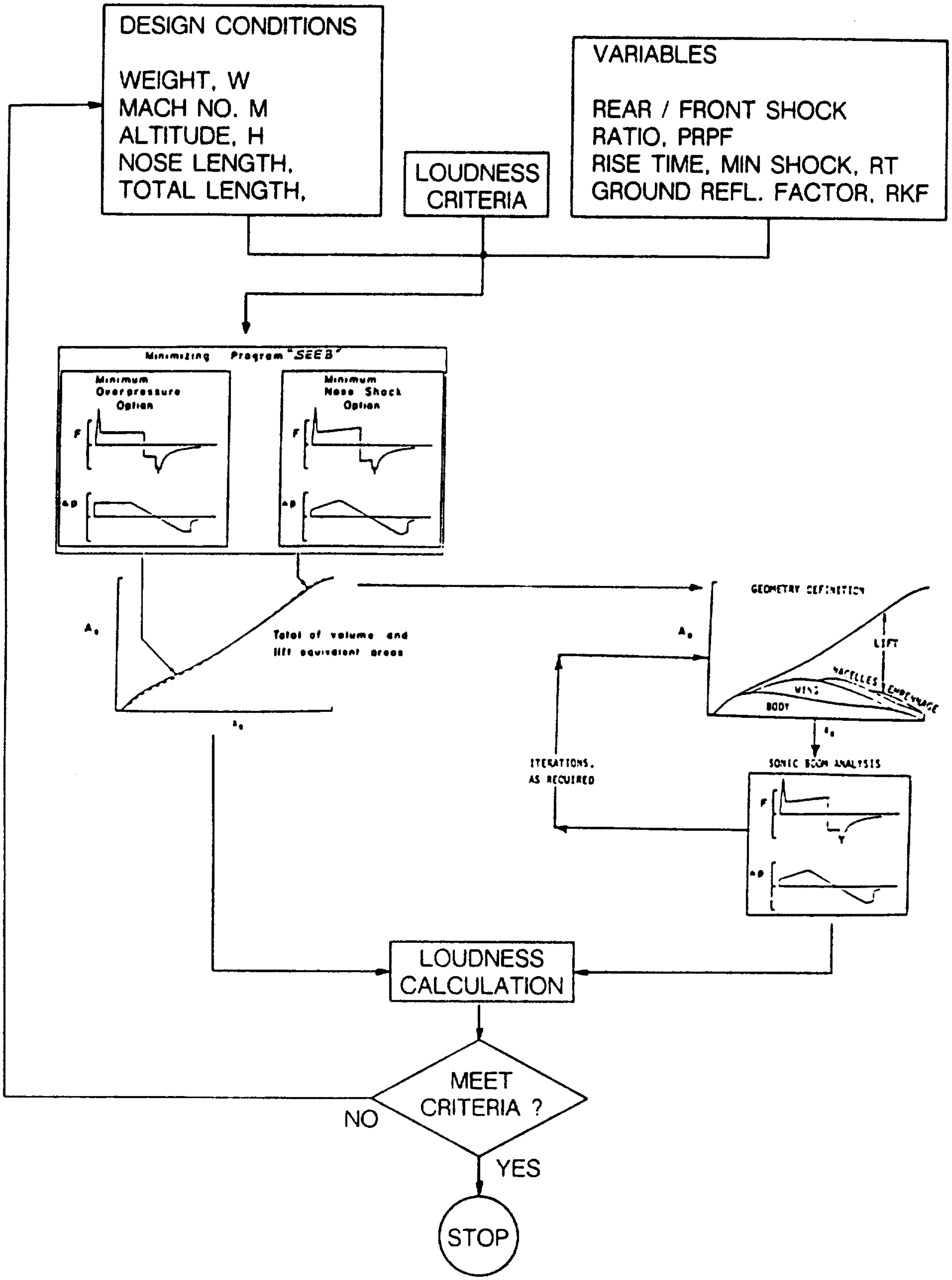


FIGURE 3.1.4-1 LOW BOOM DESIGN PROCEDURE

1080-808 AND B2707-300
TOGW = 750000 lb

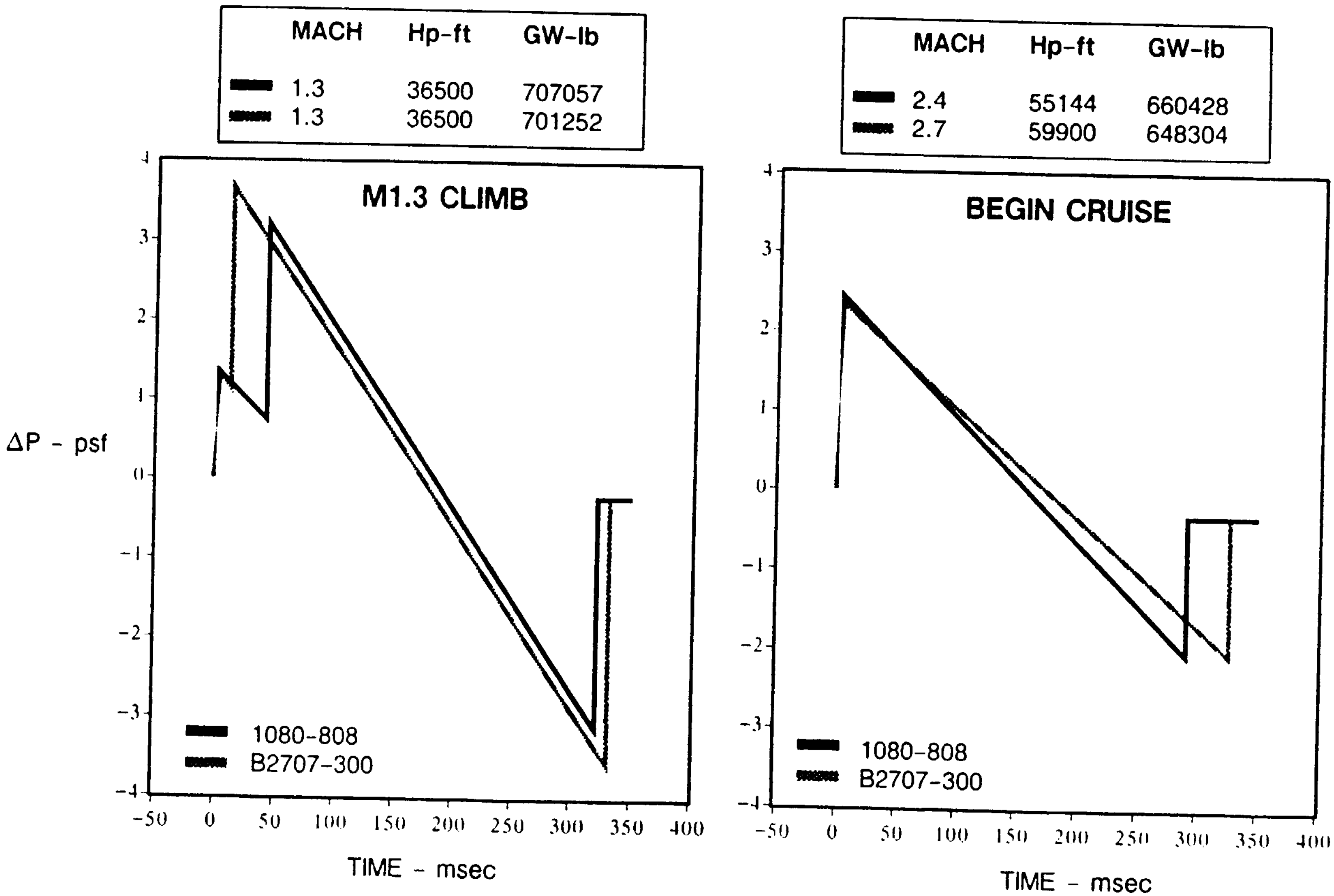


FIGURE 3.1.4-2 SONIC BOOM - PRESSURE SIGNATURES

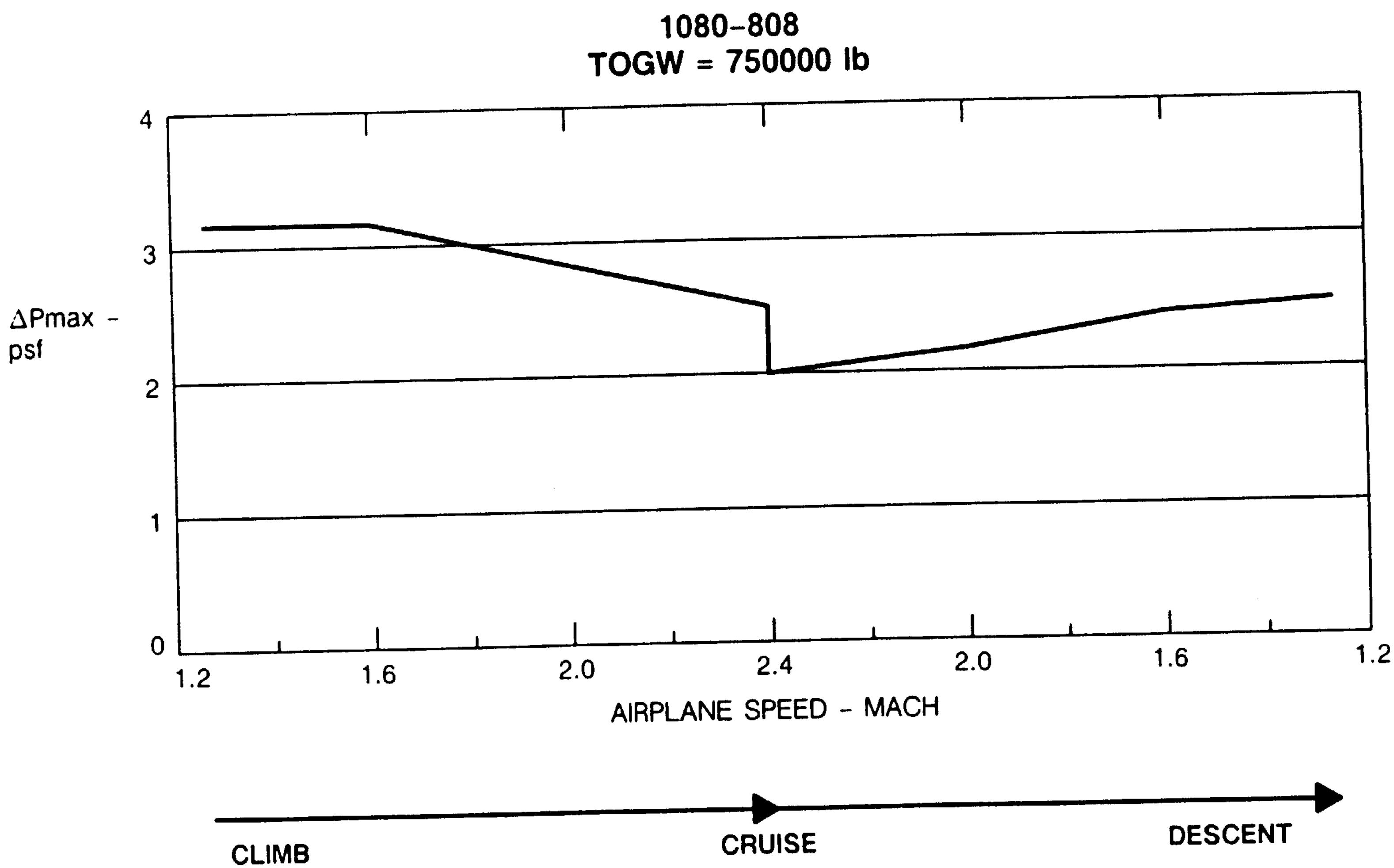


FIGURE 3.1.4-3 SONIC BOOM PRESSURE LEVEL - CLIMB, CRUISE & DESCENT

BEGIN CRUISE, M2.4
55000 FT ALTITUDE
660000 LB GROSS WEIGHT
750000 LB TOGW

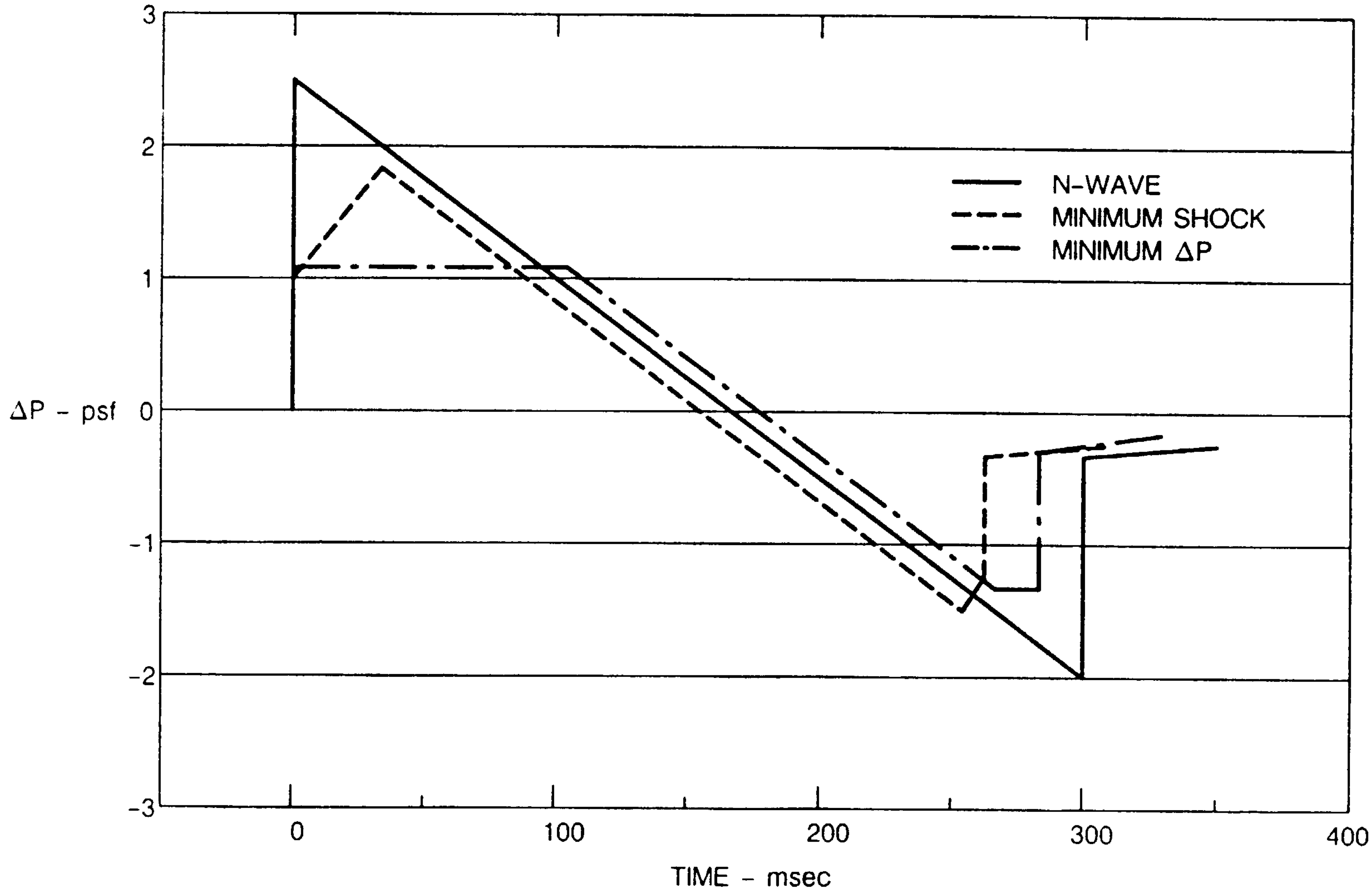


FIGURE 3.1.4-4 SONIC BOOM PRESSURE SIGNATURES, CONVENTIONAL AND LOW BOOM

Energy Spectral Density of Sonic Boom

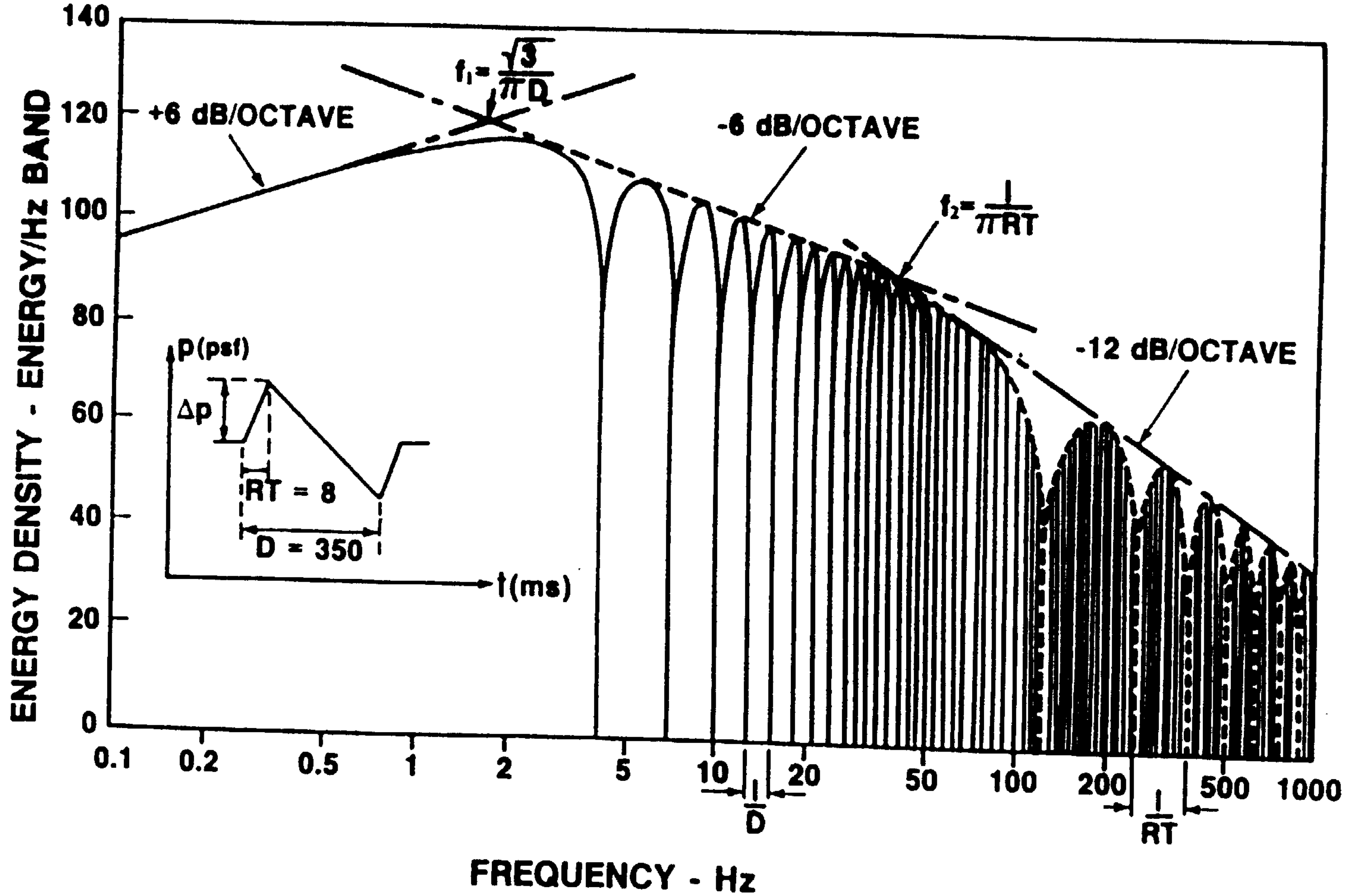


Figure 3.1.4-5

Proposed Maximum Permitted Exposure Levels

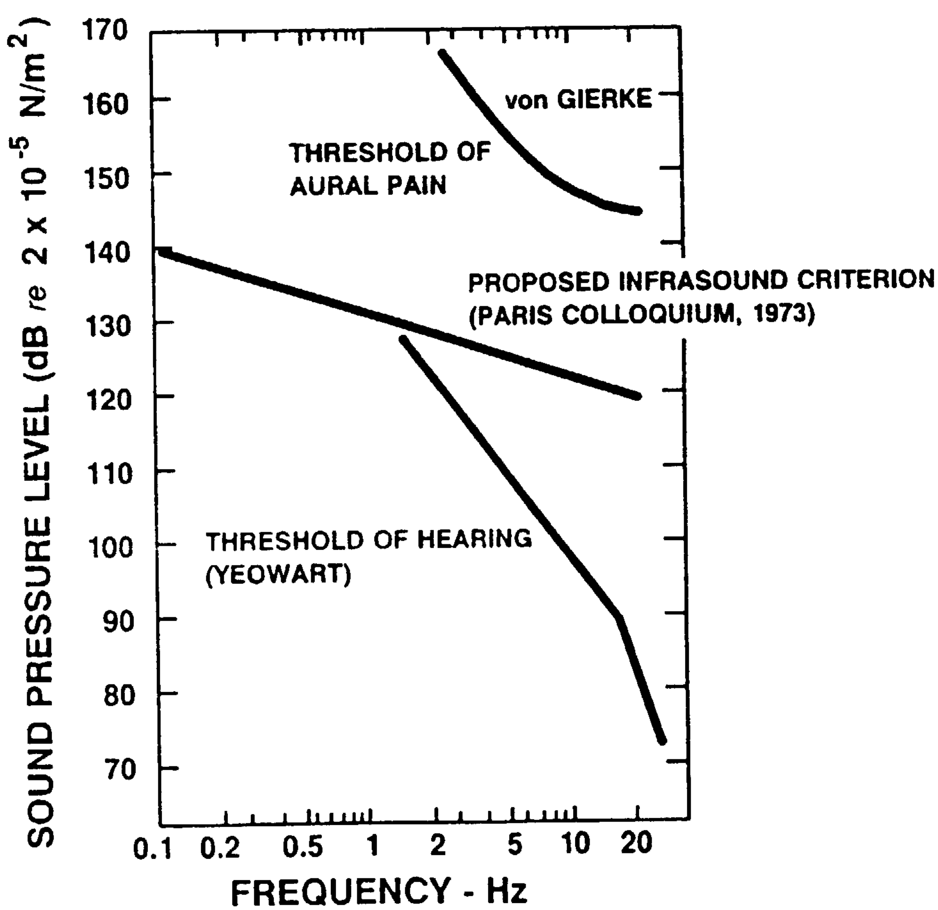
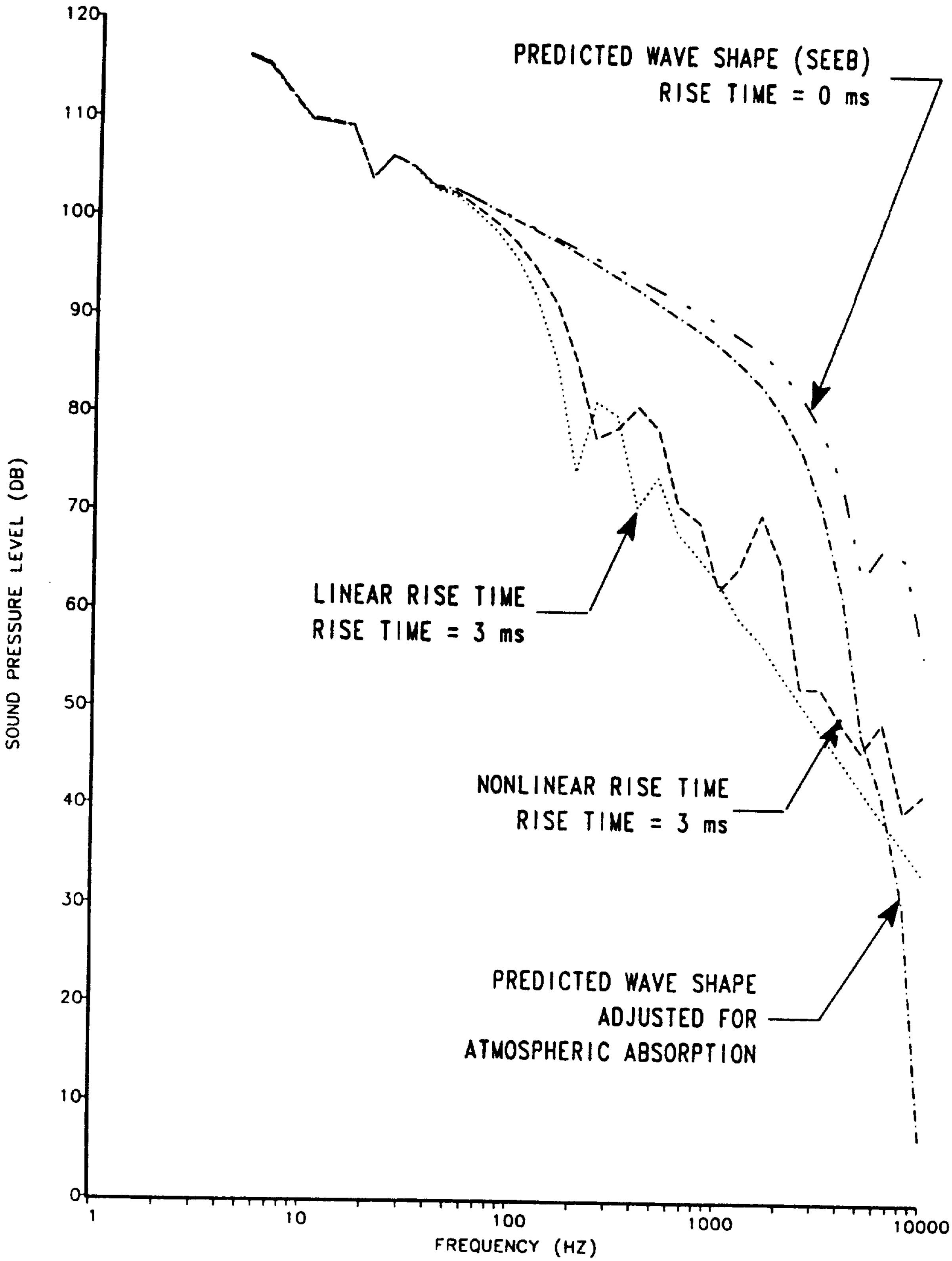


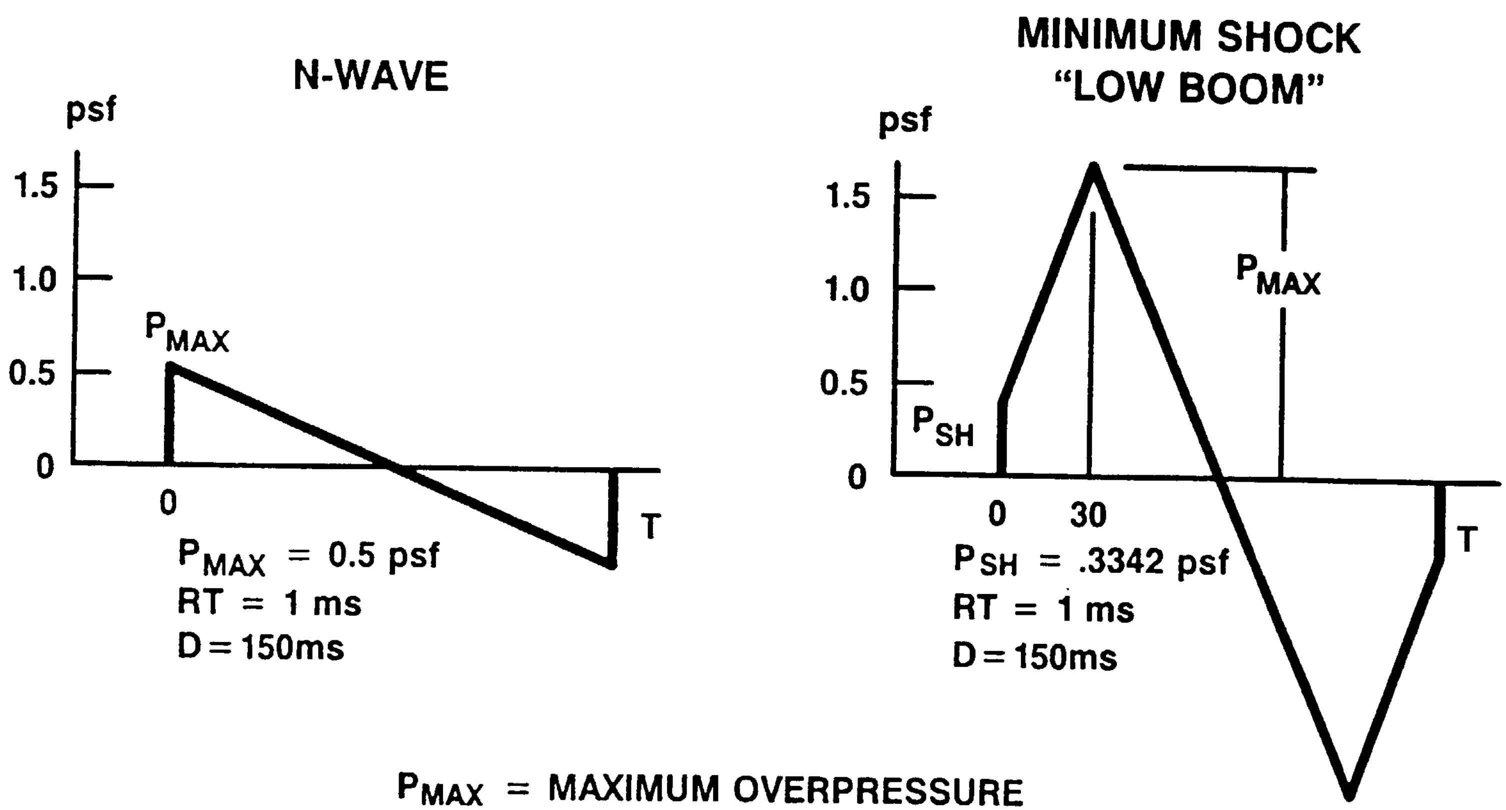
Figure 3.1.4-6

FIGURE 3.1.4-7 COMPARISON OF SPECTRA



Sonic Boom Wave Forms Judged Equally Loud

(From Niedswiecki, 1977)



P_{MAX} = MAXIMUM OVERPRESSURE
P_{SH} = INITIAL SHOCK OVERPRESSURE
RT = RISE TIME
D = DURATION

Figure 3.1.4-8

Comparison of Maximum Overpressure

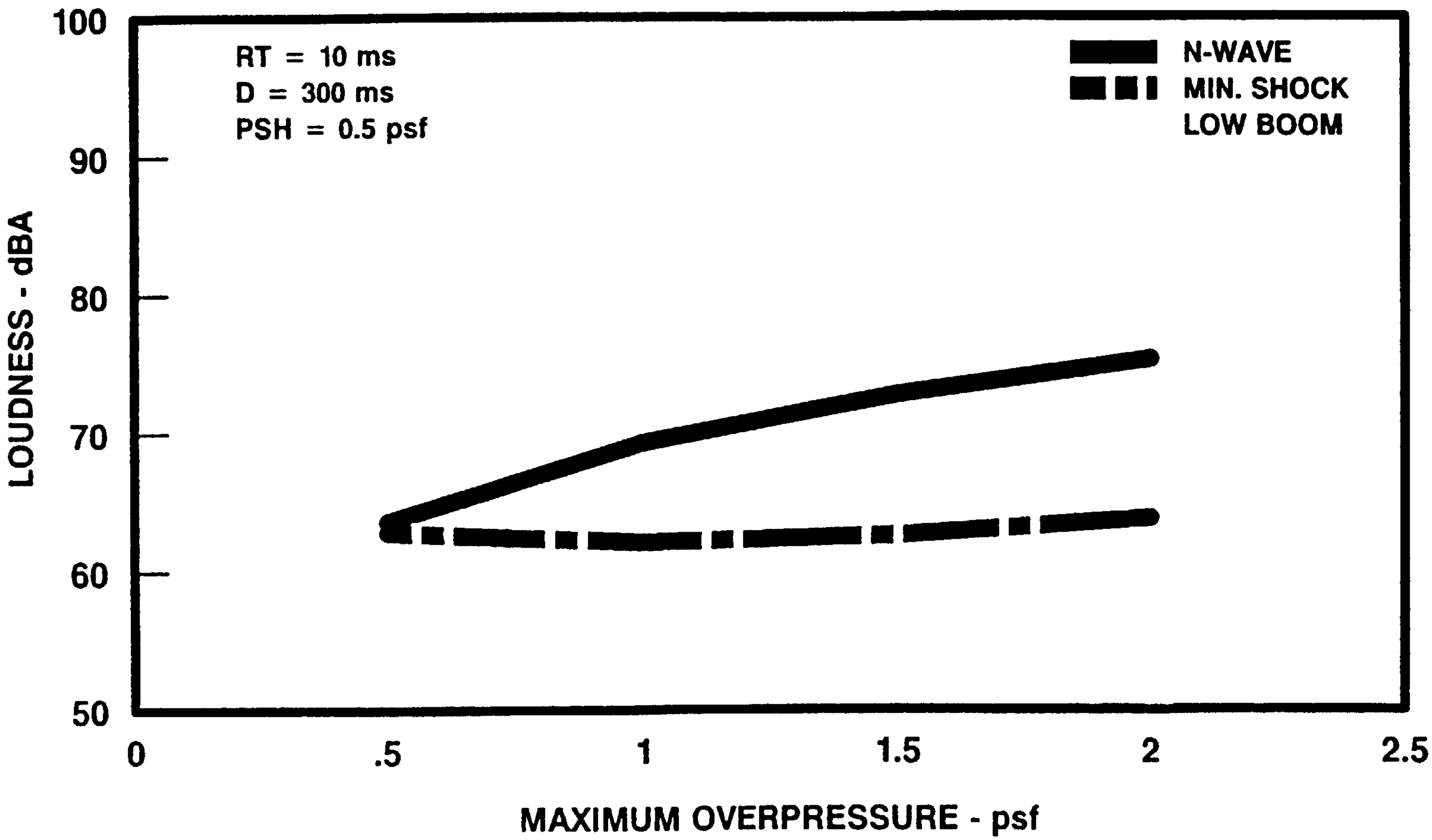


Figure 3.1.4-9

Minimum Shock Low Boom Sensitivities

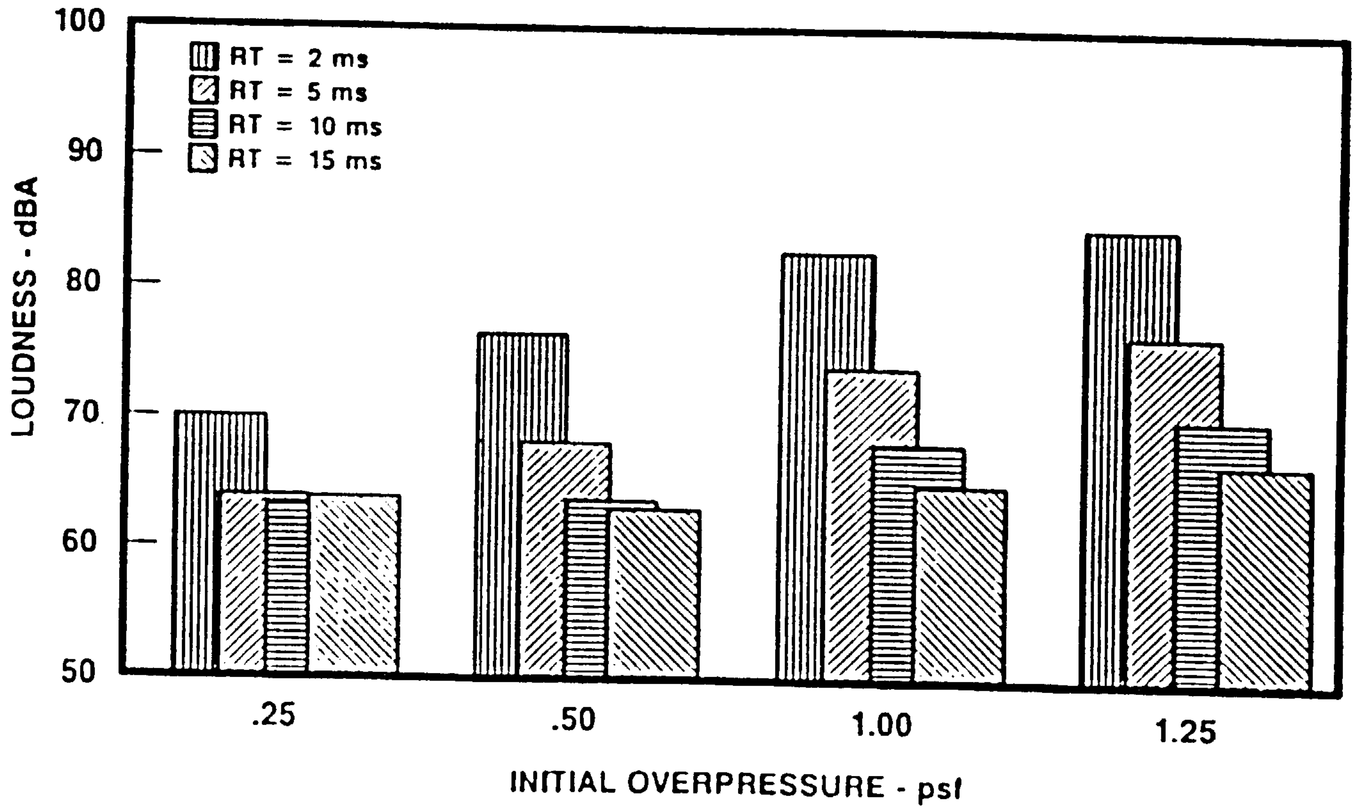


Figure 3.1.4-10

Author	Noise Level	Results	Test Condition
Higgins, Et Al (Ref 13)	70.5 dBA	80% Said Acceptable (Rated Slightly Higher Outside vs Inside)	Simulated Booms Inside and Outside
Mabry, Et Al (Ref 14)	81.0 dBA 76.5 dBA 72.0 dBA	Not Acceptable Possibly Acceptable Clearly Acceptable	Booms in Peoples' Homes 3 Levels Presented
Thackray, Et Al (Ref 15)	71.5 dBA 76.0 dBA	No Habituation Some Habituation (10% Arm Hand Movement)	Simulated Boom in Chambers

Figure 3.1.4-11 Results of Human Response Testing

Comparison of Noise Metric Sensitivity

METRIC	LOW FREQUENCY CUTOFF (Hz)	NOISE LEVEL		
		RT = 2 ms	RT = 15 ms	DELTA
dBA	1.25	83.2	66.1	17.1
dBC	1.25	108.4	103.6	4.8
MARK VII-PHONS	1.25	91.1	74.1	17.0
MARK VI-PHONS	50	97.8	82.7	15.1
ZWICKER-PHONS	50	101.7	88.8	12.9

Figure 3.1.4-12

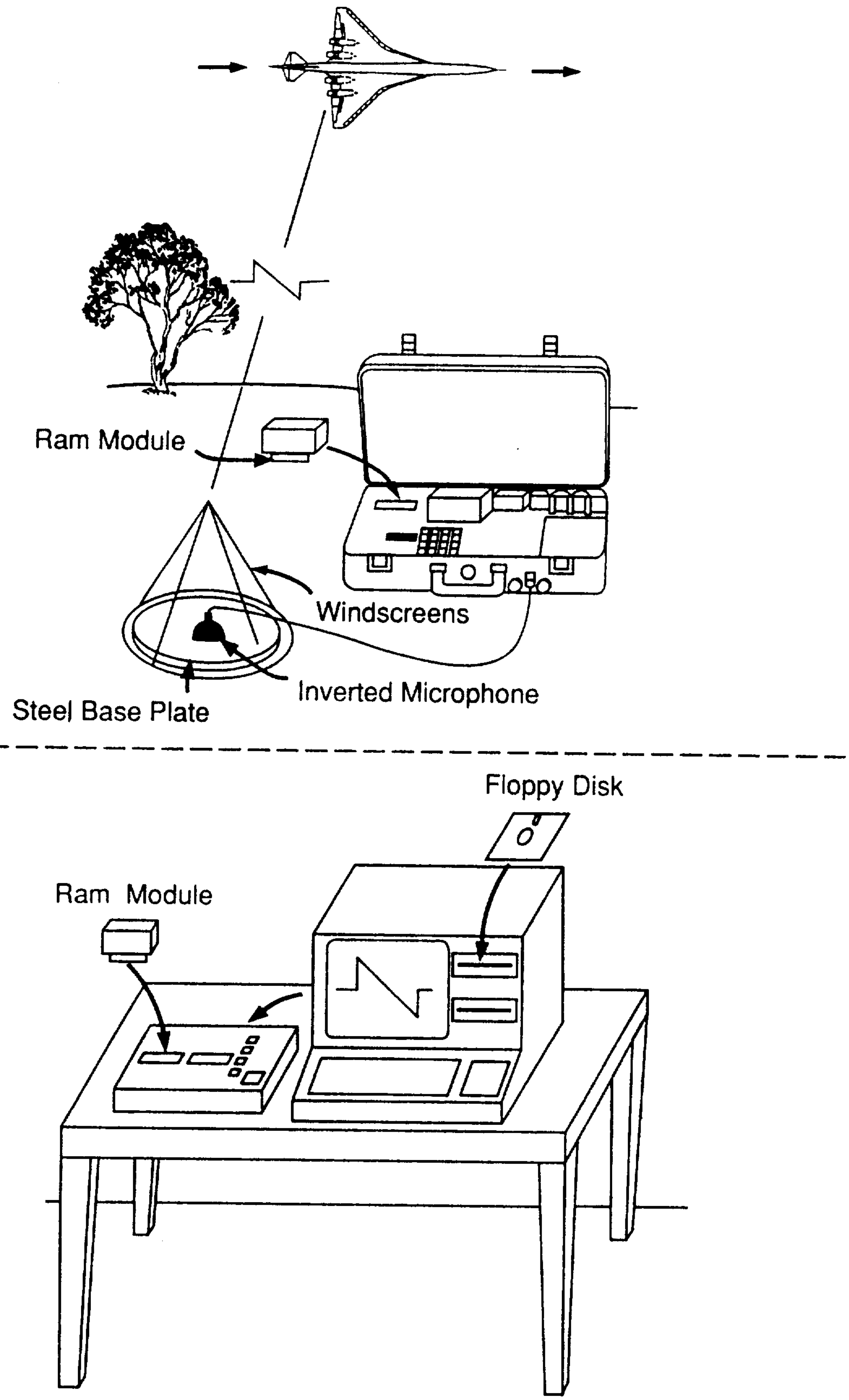


Figure 3.1.4-13 Boom Event Analyzer Recorder (BEAR)

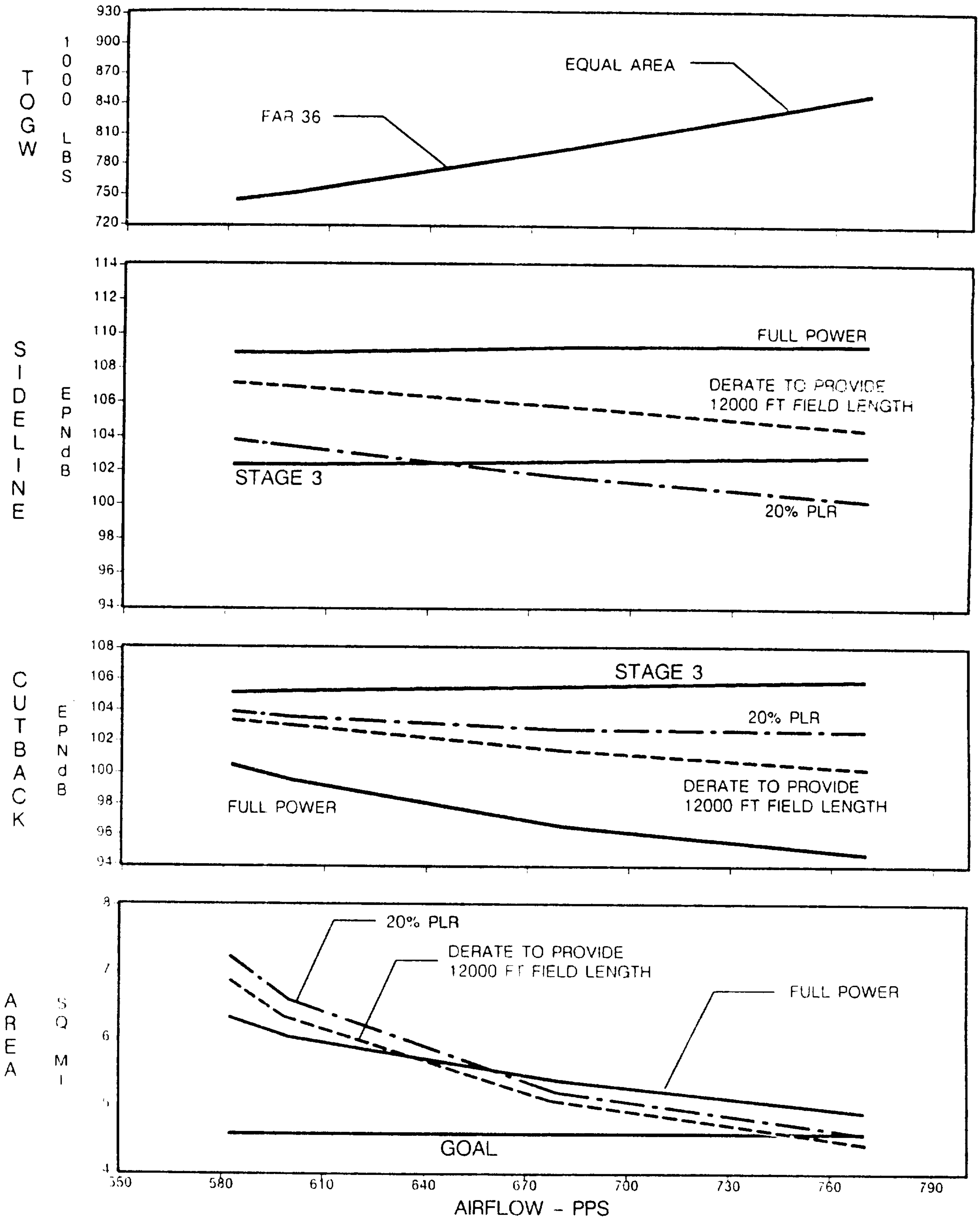


FIGURE 3.2.4-1 NOISE IMPACT STUDY RESULTS

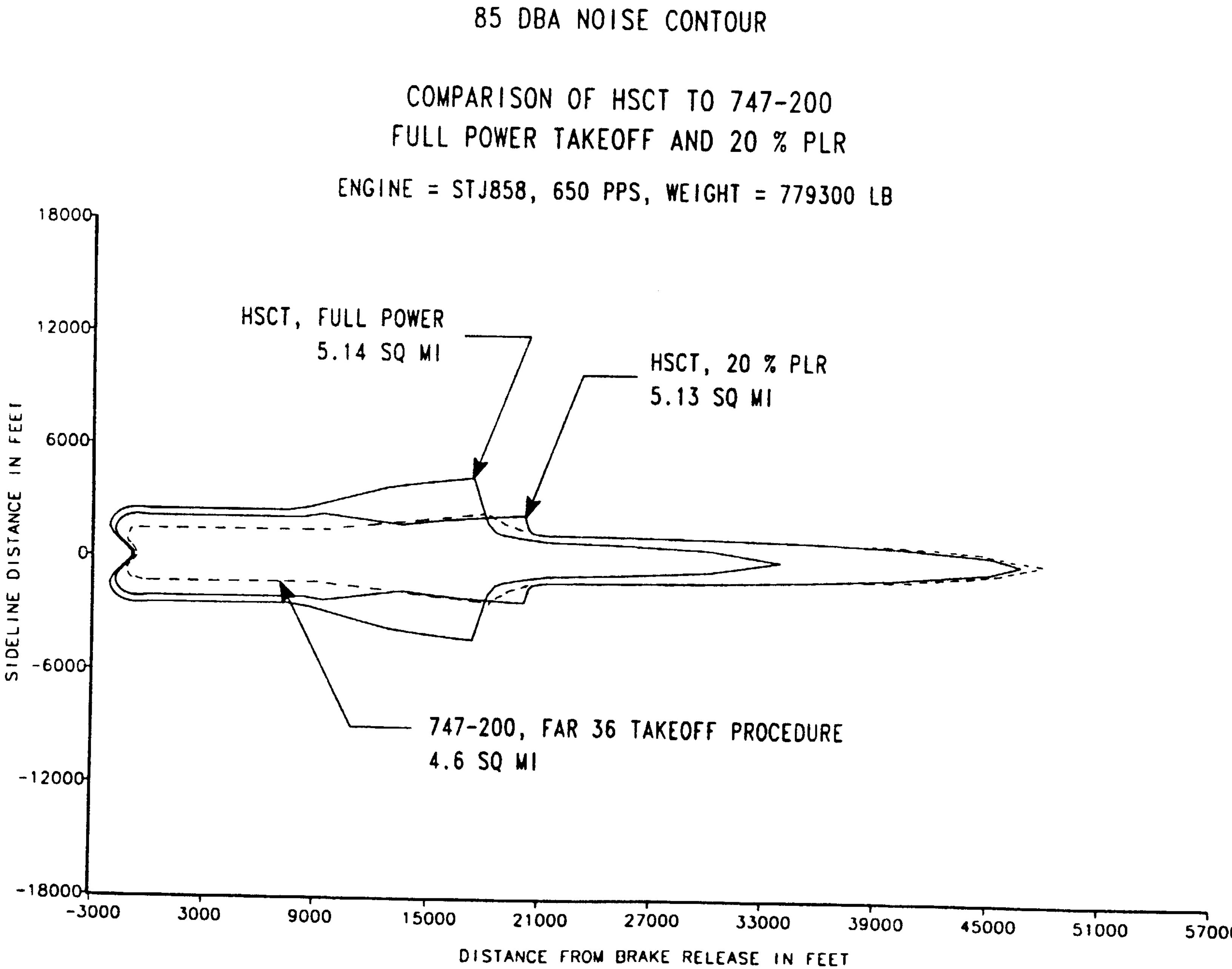

85 DBA NOISE CONTOUR
COMPARISON OF HSCT TO 747-200
FULL POWER TAKEOFF AND 20 % PLR
ENGINE = STJ858, 650 PPS, WEIGHT = 779300 LB
HSCT, FULL POWER
5.14 SQ MI
HSCT, 20 % PLR
5.13 SQ MI
747-200, FAR 36 TAKEOFF PROCEDURE
4.6 SQ MI
SIDELINE DISTANCE IN FEET
18000
12000
6000
0
-6000
-12000
-18000
-3000
3000
9000
15000
21000
27000
33000
39000
45000
51000
57000
DISTANCE FROM BRAKE RELEASE IN FEET

Figure 3.2.5-1

Community Noise Results

85-dBA Footprint - Heathrow Airport

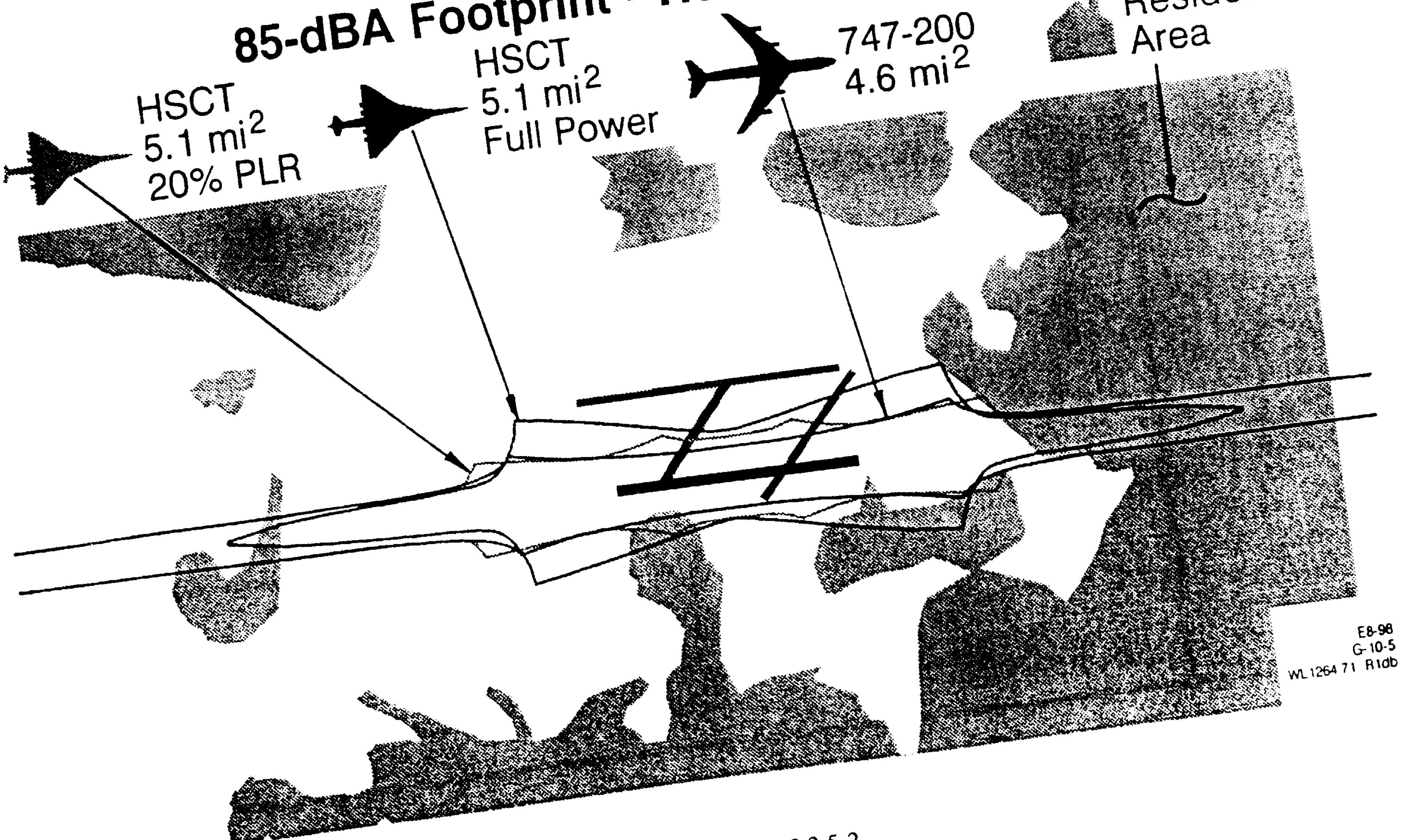


Figure 3.2.5-2

Airport	HSCT, 650 pps		747
	Full Power	20% PLR	
Anchorage	19.3	0.0	0.0
Auckland	81.9	245.8	460.8
Chicago	1555.7	3443.1	2367.5
Copenhagen	334.2	614.4	1663.0
Dallas	0.0	0.0	0.0
Dulles	0.0	0.0	0.0
Frankfurt	0.0	0.0	0.0
Heathrow	831.5	1484.8	1720.3
Hong Kong	283.0	139.3	131.1
Honolulu	3006.5	3252.2	3252.2
Los Angles	1806.3	2060.3	2187.3
Miami	1306.6	2214.7	2252.8
Montreal	0.0	0.0	0.0
Paris	1048.6	2465.0	4300.8
San Francisco	1171.5	1484.8	1929.2
Seattle	2814.0	3948.5	4423.7
Sydney	1785.9	1740.8	2048.0
Tokyo	0.0	0.0	0.0
Ave of above Airports	891.39	1282.98	1485.98
% Relative to 747	56.8%	93.5%	

TABLE 3.2.5-1 Residential Area (acres) Noise Exposure ≥85 dB Contours

Airport	Baseline HSCT 582 pps Full Power	747	% Relative to 747
Anchorage	0.0	0.0	100.0%
Auckland	294.9	460.8	64.0%
Chicago	2019.3	2367.5	85.3%
Copenhagen	1497.6	1663.0	90.1%
Dallas	0.0	0.0	100.0%
Dulles	0.0	0.0	100.0%
Frankfurt	0.0	0.0	100.0%
Heathrow	1556.5	1720.3	90.5%
Hong Kong	335.9	131.1	256.2%
Honolulu	3006.5	3252.2	92.4%
Los Angles	2456.8	2187.3	112.7%
Miami	2039.8	2252.8	90.5%
Montreal	0.0	0.0	100.0%
Paris	5529.6	4300.8	128.6%
San Francisco	2048.	1929.2	106.2%
Seattle	4669.4	4423.7	105.5%
Sydney	1794.0	2048.0	87.6%
Tokyo	0.0	0.0	100.0%
Total	27248.3	26736.7	101.9%

TABLE 3.2.5-2 Residental Area (acres) Noise Exposure $\geq$ 85 dBA Contours

4.0 FUELS

4.1 SUMMARY

The objective of this study was to identify and evaluate production, cost, property, and other non-aircraft system related factors that would effect the use of unconventional fuels in high speed commercial transports. The fuels studied included: modified conventional; endothermic; cryogenic; and others (slushes & gels). The principal work on endothermic, cryogenic and other fuels was conducted in Task 3 and reported as part of a Special Factors Assessment.[2] Tasks 4 and 7 concentrated on:

- the availability and costs associated with modified conventional fuels (referred to as Thermally Stable Jet Fuels — TSJF);
- liquid methane costs (liquid methane is assumed to be the same as purified Liquefied Natural Gas — LNG);
- on-airport costs for both conventional fuels and liquid methane.

From an economic and handling standpoint, the ideal fuel for a high speed transport would be the kerosene fuel used by currently operating commercial aircraft. This fuel, as defined by existing commercial aircraft specifications, is marginal with respect to its thermal stability even when used in today's advanced subsonic commercial aircraft. However, very few jet fuel deliveries just satisfy the minimum thermal stability requirement. In fact, test data for samples of jet fuels delivered to airports throughout the world (figure 4.1.0-1) show that over 70% of these airports currently receive fuels that satisfy a stability requirement 50 °F above the jet fuel specification minimum. This 50° improvement (a TSJFΔ) is expected to satisfy the thermal stability requirement of aircraft designed to at least Mach 2.8.

Airlines are interested in the ***price — not the cost*** — of jet fuel. The cost of fuel is composed of all direct and indirect charges to the seller. Jet fuel price is controlled by supply and demand, competition, and government policy, as well as costs. In recent history, the price of jet fuel, as well as most other petroleum products, has been considerably higher than cost, as shown in figure 4.1.0-2 Essentially, the price of petroleum based fuels are driven by supply and demand. Any petroleum refining cost differences resulting from minor jet fuel property changes dictated by the introduction of an HSCT are likely to be overwhelmed by price changes generated by competition. Even if an added cost has been overlooked in estimating the requirements for developing a supply of TSJF +50 fuel, such a cost will certainly be of a magnitude that is lost in the marketplace price variations.

Several airports are currently receiving fuels that are thermally stable beyond the limit that can be established using standard test techniques (TSJF >+150). These fuels maintain their high thermal stability from the refinery to the aircraft with no special handling or additives and they may even be as stable as natural gas or commercial grade methane. Since these fuels can be duplicated using available process equipment and techniques, the costs have been established. The portion of these costs that would be directly chargeable to jet fuel have not been determined, but would be considerably less than the 10¢/gallon recently estimated for hydrotreating distillate fuels[8]. In addition, Boeing test data indicate that fuels with very high thermal stabilities maintain their stability without costly special handling during transfer and storage.

More fuel property data and improved test techniques are required before a practical upper limit for the thermal stability of conventional fuels can be established. Current thermal stability test methods are adequate for the gross screening of fuels, but do not allow a direct correlation between test results and aircraft/engine requirements. Aircraft/engine fuel system simulations are needed to insure that a fuel

selected for use in an HSCT behaves as predicted. This is particularly important if the required stability limits are increased significantly beyond today's limits, such as for use in a >2.8 Mach number aircraft.

In past studies, available data indicated that increased thermal stability would require the acceptance of fuels with other less desirable properties, such as low density and high vapor pressure. This study demonstrated that there is no correlation between these properties and thermal stability. For example the densities of fuel samples that satisfied a TSJF >+100 requirement were within the normal scatter obtained with currently delivered jet fuels (jet A and jet A-1), as shown in figure 4.1.0-3.

New materials in HSCT aircraft and new processes producing jet fuel in modern refineries may bring the fuels into contact with catalytically active metals. Fuel analyses for extremely low (part per billion) levels of these metals will be required to insure that trace contaminants in engine emissions will not impact the production or destruction of ozone.

The petroleum product market is shifting towards premium products as shown in figure 4.1.0-4. The ability to satisfy this shift using a wide variety of crude oils and environmental considerations have resulted in a worldwide trend to increasingly sophisticated and operationally flexible refineries. This sophistication, and the fact that fuels currently delivered to most airports are more thermally stable than required by subsonic aircraft, indicate that property changes required for low Mach number high speed transports could be made with little impact on fuel price or availability. However, regardless of properties, a sudden increase in jet fuel demand precipitated by the introduction of an HSCT must be anticipated in advance to insure that entry year fuel demand can be satisfied at a reasonable price. Therefore, it is recommended that now is the time to stimulate fuel supplier interest in the increased market potential for jet fuel that would be created by an HSCT.

An important difference between the design and cost of cryogenic versus conventional fuel systems is that for cryogenic systems sizing and cost are strongly influenced by losses — vaporized liquid fuel. The design of a ground system is impacted by losses because the entire system must not only accommodate the maximum required block fuel, but liquid to replace fuel vaporized in the storage and distribution system as well as the aircraft. In addition, the design of the ground system must include a system to safely collect and recover vaporized cryogen. The cost of vaporized cryogen must be accounted for as an added fuel cost. In some cases, this gas can be sold or used in ground equipment and some of the fuel cost can be recovered. However, the vent gases must be pressurized for storage and delivered to a duty cycle and pressure level that will satisfy requirements of some yet to be identified user.

Cryogenic fuel losses, hence the cost and sizing of airport gas recovery systems, are directly influenced by aircraft duty cycle, as indicated in figure 4.1.0-5. In addition to airport-to-airport variations in losses resulting from differences in duty cycles, losses will be impacted by aircraft venting and detanking requirements. The design of methane fueled HSCT aircraft were not sufficiently advanced to determine its contribution to losses during this study and methane losses along with gas duty cycle variations shown in this report are minimums.

A key consideration in the design of cryogenic systems is the trade between the cost of thermal protection versus the cost of losses. In the idealized cases, shown in figure 4.1.0-6, a trade between expensive vacuum jacketed and less expensive solid insulations resulted in a push within the accuracy of the calculations. Even when different levels of liquid methane cost and types of financing methods were considered, no clear choice between thermal protection systems were found. However, results of this type of trade are misleading in that: vented gases are a direct out of pocket cost to the airlines; capital costs may be wholly or partially paid by municipalities or governments. In this respect, the trade is forced towards the minimization of losses.

The per unit (equivalent gallon) capital costs for fuels in this, and most other studies, is based on 100% customer utilization of facilities. Unless there is a ready market for this fuel during slack periods, there will be a significant price penalty per gallon. No such markets have been identified for liquid methane. In the case of conventional jet fuel, the facilities can be used to produce diesel or heating oil.

It was determined that all participants in an HSCT study should use the same reference prices and price ranges for thermally stable conventional fuels and liquid methane. Task 3 study results were used as support data to establish prices and ranges shown in figure 4.1.0-7. These data were further developed in Task 4 and 7. It was found that the penalties assessed to TSJF fuels are unreasonably high and should be adjusted in future aircraft studies.

4.2 INTRODUCTION

The objective of this study was to identify and evaluate production, cost, property, and other non-aircraft factors that would effect the use of unconventional fuels in high speed commercial transports. The fuels identified as offering promise for use in these aircraft included: modified conventional; endothermic; cryogens; and others (slushes & gels). The outlook for these fuels was determined and requirements for future work identified.

Results of Boeing studies covering fuels for high speed commercial transports were summarized in a paper presented at the Transportation Research Board Annual meeting.[1] These results were used as a base for a closer examination of fuel properties, availability and cost conducted in Task 3 of the High-Speed Civil Transport Studies. Results of Task 3 were reported as part of the HSCT Special Factors Assessment[2] and provided recommendations for the fuel studies conducted in Tasks 4. A principal recommendation for Task 4 was that work on liquid hydrogen should not be continued. The specific tasks recommended and carried our under Task 4 were:

- Determine the refinery capability and associated supply and demand factors that impact the availability and cost of thermally stable jet fuels (TSJF).
- Identify special TSJF delivery and airport ground support requirements and estimate their cost.
- Develop on-airport requirements and costs for liquid methane (LNG).

Recommendations developed from the studies conducted in Task 4 coupled with an emphasis on lower Mach number aircraft in the HSCT studies resulted in analyses under Task 7 that were limited to kerosene type thermally stable fuels (TSJF). Specifically these tasks were:

- Screen and characterize candidate HSCT fuels.
- Determine the factors affecting source, availability and cost.
- Determine delivery and ground support equipment (GSE) requirements.
- Identify fuel unique aircraft loading requirements.

4.3 SYMBOLS & ABBREVIATIONS

ASTM	American Society for Testing and Materials
C	Carbon
EPA	Environmental Protection Agency
GNP	Gross National Product
ΔH	Heat absorption/Enthalpy
H	Hydrogen
H_2	Hydrogen molecule
Hg	Mercury
HSCT	High Speed Civil Transport(s)
IATA	International Air Transport Association
Jet A	ASTM Specification Jet Fuel
JFTOT	Jet Fuel Thermal Oxidation Tester
JP-4	Naphtha base jet fuel used by the U.S. Air Force
KWH	Kilowatt hour
LAX	Los Angeles International Airport
LCH_4	Liquid methane
LH_2	Liquid hydrogen
LNG	Liquefied Natural Gas
M -	Mach number
MSCF -	Thousand standard cubic feet
SASOL	South African Coal, Oil and Gas Corporation
SCF	Standard Cubic Feet
T	Temperature
TSJF	Thermally Stable Jet Fuel
TSJFΔ	Same as ΔT_{bp}
ΔTbp	The difference in temperature between the JFTOT specification temperature (245°C) and the actual fuel break point temperature

4.4 STUDY RESULTS

The outlook for unconventional fuels offering promise for use in high speed commercial transport was evaluated and requirements for future work identified. The fuels covered were modified conventional, cryogenic, endothermic and other (slushes & gels).

4.4.1 MODIFIED CONVENTIONAL FUELS

From an economic and handling standpoint, the ideal fuel for a high speed commercial transport (HSCT) would be the kerosene based jet fuel used by currently operating commercial aircraft. This fuel, as defined by existing commercial aircraft specifications, is marginal with respect to its temperature tolerance even when used in today's advanced subsonic commercial aircraft. Therefore, it was considered doubtful that this fuel could satisfy the thermal stability requirements of any but the lowest Mach number supersonic aircraft. In Task 3[2], Boeing data, consultations with oil companies, and experience gained from analyzing the product output capability of oil refineries were used to assess the feasibility and practicality of increasing the temperature tolerance of kerosene type conventional fuels. This effort resulted in an indication that the majority of fuel currently delivered to commercial airports exceeded specification requirements. This indication and its implications were further explored in Tasks 4 & 7.

4.4.1.1 Options

Three options for obtaining a conventional HSCT fuel were evaluated. In the order of increasing cost and study emphasis these are:

(1) the use of a selected cut from the existing pool of conventional jet fuel or a modification to the subsonic jet fuel specification that allows its use in high speed transports.

(2) the specification of a special fuel that can be produced at existing petroleum refineries with existing equipment or a modest equipment addition;

(3) the development of a new tailored property fuel requiring totally new facilities and equipment or the addition of new facilities required to satisfy HSCT fuel demand.

In its most desirable and least expensive form, option (1) would be implemented by an adjustment to the thermal stability requirement in the existing commercial jet fuel specification (Jet A or jet A-1). Options (2) would differ from (1) only in the degree of sophistication required to satisfy HSCT fuel property and/or quantity requirements. This difference would add to the cost of the basic fuel, however, additional fuel handling costs would likely be the most significant in terms of price to the airlines.

4.4.1.2 Thermal Stability

The key characteristic that limits the use of conventional fuels in high speed transports is thermal stability (temperature tolerance). Possibilities for obtaining fuels with improved thermal stabilities were evaluated. This evaluation emphasized the development of characteristics for jet fuels currently being delivered to commercial airports because only a limited quantity of thermal stability data were available and the use of this fuel in an HSCT is the lowest cost option.

There is no meaningful test that defines the absolute temperature tolerance of a fuel. Fuel decomposition, polymerization, and coking are functions of time as well as temperature. The time for a reaction to take place is, in turn, dependent upon the presence of fuel contaminants that catalyze reactions as well as the catalytic effect of materials used in the construction of containers and tubes.

Various test procedures have been developed to establish the relative temperature stability of jet fuels. Most data of this type have been produced using the Jet Fuel Thermal Oxidation Tester (JFTOT) called out in commercial jet fuel specifications and shown in figure 4.4.1-1[3].

The JFTOT test is used to pass or fail commercial jet fuels with respect to thermal stability. The test uses the color of an aluminum tube and the pressure drop through a filter as pass or fail criteria. In its standard use, the test is run at a single temperature. As a research tool, the temperature is increased until either the tube color or filter pressure drop limit is not satisfied. This temperature is called the break point temperature. The break point temperature is an indication of relative — not absolute — thermal stability and can be used as a guide for increasing the allowable temperature limits for the various fuels. There is some question as to the reliability of using differences in JFTOT break point temperatures as an absolute basis for changing fuel temperature limits. However, break point temperature is currently the most reliable indicator available for estimating fuel temperature limits. Therefore, in this program, the thermal stabilities of fuels were based on variations from the base JFTOT pass temperature as defined in figure 4.4.1-2.

Fuel data obtained from an ongoing Boeing funded research program were used to evaluate the effects of variations in basic fuel properties on thermal stability. 43 fuel samples have been analyzed as a part of this screening. These include: the 30 samples from airports worldwide shown in Figure 4.4.1-3; military fuels; mixtures of fuels with high and low thermal stabilities; and special fuels supplied by various oil companies.

No absolute correlation between fuel composition or any fuel property and thermal stability, as measured by the JFTOT, has been identified in the Boeing program. The data do indicate that specific levels of various properties will limit fuel thermal stability. For example: none of the fuels with multi-ring aromatic concentrations >3% have been more stable than TSJF +100 as indicated in figure 4.4.1-4. No relation was found between stability and the concentration of single ring aromatics.

Fuel sulphur and acid content have been considered principal properties that limit thermal stability[4]. No absolute correlations between sulphur and/or acid content were found. However, no fuels with with an acidity greater than 0.002 and a sulphur content greater than 0.02% have been more stable than TSJF>100.

More basic chemistry work is needed to understand all of the factors that impact fuel thermal stability. This will be particularly important if kerosene type fuels are considered for use in aircraft with Mach numbers >3 (TSJF >100?). Screening test data and information as to the processing used to obtain the fuel are adequate to identify fuels with thermal stabilities up to at least TSJF +60.

The occurrence frequencies for the various levels of thermal stabilities obtained from the 30 worldwide airport samples (figure 4.4.1-5) indicate that there is little problem in obtaining jet fuel that can satisfy a TSJF +60 requirement. The availability of fuels that can satisfy a TSJF 60+ drops rapidly with temperature to slightly over TSJF 100+. Both the airport and special fuels data indicate that if a fuel can satisfy a TSJF 100+ requirement it will be stable to at least TSJF +150. More test work is required to verify this point as well as to establish an upper limit for the stability of kerosene type jet fuels.

Hydrotreated Jet fuels have high thermal stabilities, as indicated by the JFTOT test result shown in figure 4.4.1-6. These fuels typically failed the color portion of the test before any pressure drop was observed. In most cases, 100% hydrotreated fuel passed the JFTOT at the maximum practical temperature for the aluminum tubes used in the test.

The effect of mixing low and high thermal stability fuels has been evaluated. Test results indicate that: the thermal stability of mixtures is <u>not</u> limited to the stability of the poorer fuel. Relatively small concentrations of a high thermal stability fuel may significantly alter the stability of the mixture as shown in figure 4.4.1-7. More data are needed to establish the exact quantities of added fuel needed to improve, or reduce, the stability of the fuel and to evaluate different types of fuel mixtures.

4.4.1.3 Properties

Basic properties, as well as composition, were measured in the Boeing funded research program for all 43 fuel samples used in the thermal stability evaluation. In past studies, available data indicated that high thermal stability (TSJF >+100) was synonymous with low fuel density.[1,2] The more recent and larger collection of test data analyzed in this study show that this is not correct — no correlation was found between fuel density and thermal stability, as shown in figure 4.4.1-8. Fuels with high thermal stabilities that satisfy commercial jet fuel (Jet A & A-1) density requirements are currently being delivered to commercial airports.

Another property that could significantly impact the design of high speed transports is vapor pressure. As for density, test results demonstrate that there is no correlation between high thermal stability and vapor pressure, as shown in figure 4.4.1-9.

In other words, thermally stable fuels that satisfy commercial jet fuel specifications are not forced to have abnormally low densities, high vapor pressures or other undesirable property covered by these specifications. Hydrotreated jet fuels do have poor lubricity. However, the use of fuels with poor lubricity is a current subsonic aircraft problem that is being cured by the use of additives. Therefore, a requirement for such additives will create no unique problems or cost for an HSCT.

During the past several years, Boeing research has shown that there is a definite correlation between the heat content and density of hydrocarbon fuels. This relationship was checked using test data developed for the evaluation of high speed commercial transport fuels. The check showed that the correlation holds over a very wide range of fuel densities and types of fuel. This correlation could be used for a rough determination of fuel energy content — a parameter that might be critical to extending the payload or range capability of a high speed transport.

4.4.1.4 Supply & Demand

The demand for finished petroleum products (unleaded gasoline, jet fuel, diesel, and petrochemicals) is increasing while the demand for fuel oils (residual and home heating oil) is declining. This trend can be expected to continue through the end of the century as shown in figure 4.4.1-10. The year 2000 demand takes into account the increasing worldwide mobility of people, the continuing improvement in energy efficiency (decreased energy per GNP), and the worldwide concern about and commitment to reducing pollution.

Total gasoline demand (leaded and unleaded) will continue to decline as fuel efficiencies improve and the real price continues to increase in spite of near constant production cost. The price increases will come about as the result of increased pressure to find new sources of government monies (added taxes) which will:

- exert downward pressure on gasoline demand because it is a large out of pocket cash expense;
- provide incentive for continued down-sizing of cars and the development and application of high performance technology, such as fuel injection.

Counteracting the downward trend in demand for gasoline will be an increasing demand for jet fuel and diesel. World revenue airline passenger miles are expected to double by the year 2000, however, fleet fuel efficiency will improve about 25%. As a result, jet fuel consumption will increase about 50%[5]. Travel to the Pacific Rim nations is expected to increase rapidly and these nations will have the fastest growth in jet fuel. The popularity of diesel for light trucks and cars has declined sharply, however, diesel for heavy pickups and medium duty trucks is gaining in popularity. Dieselization of these 2 categories and all other heavy duty vehicles will continue to increase the demand for distillates.

The switch from metals to plastics in automobiles, building/construction, and packaging is increasing the demand for petrochemical feedstocks. These raw materials are a major portion of the category "other" which is also increasing. The products losing market share are home heating oil and other fuel oils (residual) which are being replaced by natural gas, coal, electricity, or by reduced demand brought about by improvements in efficiencies.

Environmental concerns are becoming more important in determining refining trends than economic conditions. An example is the phaseout of lead in gasoline (approximately 75% is unleaded). New proposals resulting from concern about acid rain and air quality include reducing the sulphur content in diesel and reducing the vapor pressure and benzene content of gasoline. The diesel fuel sulphur limit in the Los Angeles basin has already been restricted to 0.05%, a limit considerably lower than the 0.5% limit called out in the diesel fuel specification[6]. The environmental restrictions would require refiners to add processing equipment to their refineries,[7] including equipment that will add hydrogen to all streams used to make jet fuel. An increase in hydrogen will improve the thermal stability of the jet fuel pool.

All refineries are required to transform crude oil into a slate of saleable products. In the past this has been a relatively simple process of distilling the crude oil into fractions. However, the demand for gasoline has outstripped the demand for other products available from distilling crude oil. As a result, refiners have been trying to squeeze as much gasoline out of each barrel of crude as possible. Refineries have emerged from simple stills with thermal cracking of heavy fuel oils into highly sophisticated chemical factories making a wide variety of products including petroleum gases, gasoline, jet fuel, diesel, fuels oils, lubricants, waxes, and chemicals. To meet the high demand for transportation fuels and other refined products, refiners are adding processing equipment to their refineries as indicated in figure 4.4.1-11. Even more sophisticated processing equipment will be needed to meet projected product demand changes for the year 2000.

Processing the heavier crude oil fractions into gasoline, jet fuel, and diesel requires breaking large molecules into smaller ones while either rejecting carbon or adding hydrogen. An example of equipment that rejects carbon is a coker or a fluid catalytic cracker Equipment that add hydrogen include hydrocrackers, hydrotreaters, and hydrorefiners.

All refineries use some kind of thermal operation (coking, thermal cracking, or fluid catalytic cracking) to reject carbon. The quantity of these carbon rejecting processes is increasing in the world as indicated by the increase in coke production shown in figure 4.4.1-12. In this type of process the rejection of carbon serves to increase the hydrogen content of the remaining products.

An increasing amount of hydrocracking equipment is being added to both U.S. and world refineries (figure 4.4.1-13). Control of the cracking process gives a refinery the flexibility for changing the product emphasis to either gasoline or distillates (diesel and jet fuel). Hydrogen is continually used to reduce carbon build up on catalysts, to stabilize the product (eliminate olefins), and to remove impurities such as sulfur and nitrogen. Hydrocracking provides refiners with the flexibility for processing a wide variety of crudes and for meeting rapid changes in product demand. A supply of hydrogen gas is required for all hydroprocessing and its cost is often used as justification high cost estimates for fuels with high thermal stabilities. However, much of this hydrogen cost would not be chargeable to thermal stability improvement and its source would not be all from a raw-material-to-hydrogen production plant (manufactured hydrogen).

There are three sources for the hydrogen needed for today's petroleum products in addition to that found in the starting crude oil fractions. They are: 1) hydrogen enrichment, 2) manufactured hydrogen, and 3) hydrogen generated from reformers. Hydrogen enrichment is obtained through carbon rejection as previously discussed. Manufactured hydrogen (the most expensive source of hydrogen) is made from refinery by-product gas streams or from natural gas. The refinery requirement for manufactured hydrogen is increasing as shown in figure 4.4.1-14. However, this increase is being dampened by an increased availability of low cost by-product hydrogen from reformers.

Reformers used in the manufacture of gasoline are a major source of refinery hydrogen. This process increases the octane of gasoline by forming cyclic compounds and as a result, hydrogen is removed. In the U.S., refinery reformer capacity has grown slowly in the last several years with refiners having over anticipated the switch to unleaded gasoline and under estimated the progress in new catalyst development (figure 4.4.1-15). Even though reformer capacity has increased slowly, the type of catalyst has changed and the severity (hydrogen saturation of the molecules) at which this equipment operates has increased, resulting in greater productivity from the installed capacity. This has resulted in the production of higher octane gasoline and more by-product hydrogen that can be used to upgrade other refinery products. The increasing fuel efficiency of cars with the resulting need for higher octane, clean-burning fuel to maintain performance will continue to press refiners to reform fuels in the U.S. Requirements for reforming outside the U.S. can be expected to increase dramatically as a switch to unleaded gasoline is mandated and the time schedule is accelerated.

The demand for high octane blending components for unleaded gasoline has led to the development of specialized techniques for separating reformer products. The reforming process does not convert 100% of the product into cyclic compounds (high octane components). Some straight chain compounds (paraffins and isoparaffins) are in the product stream. Separation by extracting the cyclic compounds from the straight chain compounds improves fuel octane. The paraffin by-product stream which is approximately 5% of reformer capacity is becoming a product without a home. This product is too low in octane for gasoline, too high in vapor pressure for diesel or home heating oil, and too large a quantity to blend into JP-4. This material is currently being blended into jet fuel to the limit allowed by pipeline restrictions on flash point. Attempts to sell this product are putting downward pressure on JP-4 prices. *[The price of JP-4 (54¢/gal) is as much as 6¢/gallon less than Jet A (60¢/gal) even though JP-4 has special additives, is bought in small quantities, and requires special handling.]*

The hydrogen generated as a by-product of reforming is recycled for use in other hydrotreating or hydrocracking operations and along with manufactured hydrogen is being used to remove sulfur and other contaminants, to obtain usable products from residual fuel oils, and to improve diesel cetane. Jet fuel is a copartner recipient of this hydrogen and receives benefits – lower sulfur content and improved thermal stability. The flow of hydrogen is out of the gasoline fraction and into the jet fuel and distillate fractions (figure 4.4.1-16). Jet fuel receives a share of the available hydrogen – without being specifically requested through a specification or by contract.

The International Air Transport Association (IATA) has changed the JFTOT thermal stability test temperature from 245°C to 260°C, an increase of 27°F, with no impact on supply or price. In Brazil, the JFTOT temperature was temporarily raised to 275°C (TSJF +54) in an attempt to cure a local fuel problem. The refinery actually supplied a fuel with a break point temperature above 300°C (TSJF >+100)[8]. When required, refiners have been able to make modest increases in jet fuel thermal stability without equipment additions. Their ability to do this in the future should improve as more and more hydrogen is required to satisfy the demands of a changing product mix and environmental regulations.

4.4.1.5 Delivery, Storage, and Loading

An evaluation was conducted to identify equipment or facility items that could have a major impact on the cost of delivering a petroleum derived thermally stable jet fuel (TSJF) to an HSCT.

Data obtained during this evaluation indicate that the petroleum product pipeline system now used to deliver jet fuel is quite flexible and could handle the delivery of any fuel that did not require new pipeline system materials or inert gas transfer. The fuel quantities required for high speed transports are large enough to be covered in the current tariff rates established for pipeline transfer as shown in Figure 4.4.1-17.

An evaluation of thermal stability and basic property data for fuel samples taken at airports indicate that:

- no new or unusual storage or handling precautions will be necessary for the delivery, storage, or loading of fuels being considered for current study aircraft — TSJF ≥+50.
- delivery precautions may even be unnecessary for jet fuels with thermal stabilities as high as TSJF +150.

Airport facilities and fuel handling procedures will be essentially the same as for subsonic fuels as indicated in figure 4.4.1-18. Provisions for the introduction of additives may be required for the use of TSJF>+50 fuels (the use of additives in jet fuels is not new and this requirement would not be considered unique to high speed transports). Lined storage tanks and isolated delivery lines may be required for TSJF>+100 fuels. However, test data have not shown this to be a requirement. Lined tanks may already be available at many airports by the year 2000 because of pending EPA requirements that will require upgrading of existing jet fuel storage and transfer equipment. The final version of these regulations may even include airport fuel hydrant systems.[9] In any case, a better understanding of thermal stability improving additives is highly desirable because the ability of a refiner to "fix" a fuel property can significantly impact fuel price.

New materials in HSCT aircraft and new processes producing jet fuel in modern refineries may bring the fuels into contact with catalytically active metals. Tests were conducted to determine the presence of these metals in jet fuel samples selected for their unusually low thermal stabilities. These tests included a search for nickel, copper, chromium, iron, and platinum — metals that could enter the fuel during refining, distribution, and storage. Copper was the only metal found in the eight samples analyzed. This copper was in one of two airport samples that had a thermal stability (TSJF +11) lower than required by the new IATA thermal stability guidelines (TSJF +27). New information obtained about the activity of these metals indicate that the sensitivity of the technique used to detect metals in these tests was not adequate for a conclusive evaluation of metal effects. Detection limits for copper, nickel, and chromium were 0.1 parts per million; 1.0 part per million for iron and platinum. A 0.01 part per million concentration of these metals could effect thermal stability. Such precise analyses will be critical to an HSCT if:

- new materials used in the high speed transport fuel system contain catalytically active metals, such as chromium and nickel;

- trace contaminants are likely to result in emissions that impact the production or destruction of ozone.

4.4.1.6 Costs

A study result reported in Task 3[2] was that significant increases in the temperature limits of conventional jet fuels could be obtained with relatively modest cost increases, as shown in figure 4.4.1-19. In addition, it was determined that hydrocarbon fuels may have higher than previously assumed temperature limits.

Task 3 results were used as support data in establishing fuel prices to be used by all participants in the NASA study. These prices, shown in figure 4.4.1-20, were examined further in Tasks 4 and 7. Evaluations of thermal stability data for fuels currently available at refineries show that cost penalties assessed to conventional fuels for increasing their thermal stability are unrealistically high.

Answers to two key questions were expected to significantly impact previous cost estimates for TSJF jet fuels. These questions were:

- what is the thermal stability of jet fuels currently being delivered to airports?

- what special provisions are required to improve or maintain fuel thermal stability after the fuel leaves the refinery?

Test data covering the worlds airports indicate that over 90% of the airports receive fuel that can satisfy a TSJF +50 requirement (figure 4.4.1-7). The fuel samples used for thermal stability determinations received no special handling, were stored in standard steel containers and had no thermal stability improving additives. In all cases, the time from airport to fuel test (>3 months) was longer than that which is typical for a jet fuel to go from the refinery to airplane (<6 weeks). Therefore, as far as TSJF +50 fuels (fuels that are satisfactory to at least Mach 2.8) are concerned, no cost penalty can be identified

Insufficient data were available to determine actual cost penalties for TSJF >+100 fuels. However, test data indicate that highly hydrotreated fuels can not only satisfy a TSJF >+150 requirement (satisfactory for >Mach 4?), they can be maintained at this stability level with no special storage, handling or additives. Since airports are currently receiving such fuels and they can be duplicated using available processing equipment and techniques, no scenario could be developed that would lead to cost penalties greater than

10¢ per gallon for even the most stable type — highly hydrotreated — kerosene based jet fuel (10+ ¢/gallon and higher cost penalties have recently been estimated for these fuels at recent meetings).[10]

The effect of mixing high thermal stability fuels to improve a blend and the effect of additives on thermal stability are cost related questions that remain to be answered. If it is determined that blending or additives improve the thermal stability of existing jet fuel sources, the improvement cost would be insignificant. For example: the added costs to jet fuel for two thermal stability improving additives available from Dupont are:

- DMD-2 Metal Deactivator ~0.03 ¢/gallon
- JFA-5 Thermal Oxidation Improver ~0.06 ¢/gallon

There would be an at-airport cost for storing and mixing the additives. However, this type of cost is within the basic ***price*** structure for current jet fuels.

Airlines are interested in the ***price not the cost*** of jet fuel. The cost of fuel is composed of all direct and indirect charges to the seller. Jet fuel price is controlled by supply and demand, competition, and government policy as well as costs. The cost of jet fuel from petroleum is driven by the price of its raw material, i.e. crude oil, the cost of capital and refinery operating costs. If it is assumed that the raw material (crude oil) owner is the seller of jet fuel; the cost of this fuel ranges between 9 to 67 ¢/gallon, as shown by the breakdown in figure 4.4.1-21 (owner to seller control of the petroleum based fuel market is becoming more common as the producing nations get involved in downstream activities).

In recent history, the ***price*** of jet fuel, as well as most other petroleum products, has been considerably higher than cost, as shown in figure 4.4.1-22. Recently, the price of petroleum based fuels have been driven by supply and demand in spite of attempts by various governments to control the price of crude oil. Any cost differences resulting from minor changes to the jet fuel supply required by the introduction of an HSCT are likely to be overwhelmed by competition generated price changes. Even if an added cost has been overlooked for TSJF +50 fuels it will certainly be of a magnitude that is lost in the marketplace.

Extra costs that will be directly charged to jet fuel may be modest even for TSJF >+100 because:

- all middle distillate are likely to be more severely hydrotreated in the future because of new environmental rules controlling sulphur content.

- increased hydrotreating is leading to a surplus of both the light end of the diesel fuel range and the low octane by-products of gasoline production — both fractions tend to have high thermal stabilities; both need a customer.

- progress in the development of processes for the synthesis of natural gas into middle distillates may provide an abundant source of high thermally stable fuel in the early part of the next century.

4.4.1.7 Recommendations

Results of analyzing test data and an evaluation of test methods indicate that:

- It is unnecessary to change fuel property requirements, such as for density and vapor pressure, to obtain thermally stable kerosene type jet fuels. Therefore, fuels screened for thermal stability should be limited to those with properties considered desirable for use in jet aircraft.

- The research version of the Jet Fuel Thermal Oxidation Tester (JFTOT) is adequate for the gross screening of fuels. However, it is suggested that the modifications shown in figure 4.4.1-23 be examined to determine if the test can be changed to more closely represent the thermal conditions found in aircraft and engines.

- A rudimentary thermal simulator should be used for the final selection and behavior verification of HSCT fuels.

A sufficient number of fuel tests were conducted to establish that fuels with higher thermal stabilities than required by subsonic aircraft are currently being delivered to most of the world's airports. It is recommended that further testing be conducted to:

- Define the upper stability limit for a single fuel that can satisfy both subsonic and supersonic aircraft requirements (this will require a better understanding of how JFTOT test data relate to actual aircraft/engine temperatures, heat fluxes, and residence times).

- Evaluate the thermal stability of selected jet fuels at the refinery, at the airport, and immediately prior to aircraft loading (this will probably require the involvement of non-U.S. jet fuel facilities since tracing a particular fuel from a refinery to an end user is extremely difficult in the U. S.).

- Precisely analyze (part per billion level) candidate HSCT fuels for trace metals that could impact the environment — ozone formation or destruction.

Supply/Demand and economic analyses show that insuring that producers will be able to provide the quantities and quality of fuel required to satisfy HSCT entry year fuel demand is at least as important as technology development. Now is the time to interest fuel suppliers in the increased market potential for jet fuel that would be created by an HSCT.

4.4.2 CRYOGENIC FUELS

The production methods and costs of cryogenic fuels (liquid hydrogen and methane) for commercial aircraft were conducted and reported as part of the HSCT Task 3 Special Factors Assessment.[2] The work resulted in the conclusion that the cost of cryogens is a key deterrent toward their use in commercial aircraft. The most optimistic basic costs for hydrogen and methane are higher than the current price of conventional jet fuel (Jet A). In addition to the basic fuel cost, cost penalties must be added for: ground and aircraft vaporized fuel losses; and construction of new airport fuel distribution, storage, and aircraft servicing equipment. Evaluations of liquid hydrogen were not continued beyond Task 3 and liquid methane/liquefied natural gas (LNG) studies were concerned primarily with on-airport requirements and costs. For the simplicity of the study, the term liquid methane covers LNG unless the difference between the two are important to the particular item discussed.

4.4.2.1 Design Considerations

The magnitude of vaporized liquid losses in a cryogenic system are directly related to the effectiveness of the thermal control provisions. This includes the control of heat losses through supports and equipment as well as insulation. The design of equipment and choice of insulation for an airport fuel system must be based on a cost trade that balances the cost of total losses with cost of thermal protection. This trade must recognize cryogen delivery rates and saturation pressures that can satisfy off-nominal as well as nominal aircraft fuel loading, cooldown, maintenance and detanking requirements. These aircraft requirements establish the design base for a ground system that must handle wide variations in flow rates as well as deliver a cryogen that will not flash vaporize at loading pressures close to ambient.

Regardless of any improvements in the efficiency of an airplane resulting from the use of a cryogen, the size of the liquid storage and delivery portion of the ground support equipment will be considerably larger than for conventional fuels due to their low volumetric energy content (shown in figure 4.4.2-1). This size increase is further magnified by the extra liquid that must be added to account for total vaporization losses. In addition, totally new systems must be provided to safely collect, store, and dispose of all vented gases.

It is universally recognized that cryogens must be stored in insulated pressure vessels and delivered through insulated transfer lines. What is not recognized is that an aircraft must receive the cryogen in a subcooled state with respect to its fuel tank vent back pressure. This has been the single most difficult condition to meet in designing aircraft cryogen loading systems that must satisfy both a variable loading schedule and a fast turnaround requirement. Such a problem is not encountered with conventional fuels unless they are loaded above their ambient boiling point; a temperature well above 100 °F as shown in figure 4.4.2-2.

4.4.2.2 Supply

The overall world supply of natural gas for use in the production of methane has not been identified as a problem. However, it is questionable if gas will continue to be available from countries (Algeria, Nigeria and Indonesia) that are forced to price their gas at a level such that its cost after liquefaction will be sufficiently low to be cost competitive with petroleum. In addition, new technologies for the synthesis of gasoline and middle distillate type fuels has advanced close to the point where the liquefaction of gas in areas that have local market will no longer be necessary or cost effective.

4.4.2.3 Delivery, Storage, and Loading

Vaporized liquid losses and their disposal at an airport can add a significant penalty to the use of cryogen fuels. To date, it has been assumed that vaporized methane, or hydrogen, would be purchased by the local gas utility company at market price, thus the only cost penalty would be a liquefaction cost. However, the cost penalty and disposal method associated with these losses is highly dependent upon the airport arrival/departure duty cycle. Therefore the vaporized cryogen disposal method, and associated cost penalties, cannot be determined without at least:

- identification of liquid storage and distribution equipment insulation effectiveness.
- an estimate of total aircraft and ground equipment liquid vaporization losses along with the gas flow duty cycle.

Total liquid losses for methane and the associated gas flow duty cycle were calculated using the Los Angeles airport (LAX) as a model. It was estimated that 2.6 million equivalent jet A gallons of methane would be loaded per day for 65 departures of Mach 3.8 aircraft. The aircraft departure schedule used to estimate the vent gas duty cycle for LAX is shown in figure 4.4.2-3.

Cryogen gas handling equipment must be designed to handle: liquid storage tank losses; liquid distribution and conditioning system losses; and vent gas from aircraft cooldown, loading, and boiloff.

Adequate data were not available for an accurate estimate of aircraft cooldown and boiloff losses since they are highly configuration dependent. Therefore, a vent gas duty cycle was calculated for an idealized system using aircraft with precooled and highly insulated tanks — in effect, a minimum aircraft loss case. However, even with zero heat leak precooled tankage, there are still losses associated with the aircraft loading. These losses include:

- Blow Down — The vapor released when the aircraft vent is opened and the cryogen is resaturated at the fuel tank loading pressure.
- Vapor — The vapor displaced by the liquid loaded in the fuel tank.
- Pressurization — The liquid vaporized to attain the fuel tank operating pressure.

The magnitudes of these losses are influenced by the tank ullage volume (vapor space), hence are dependent upon the quantity of liquid remaining in the tank prior to refill, as shown for methane in figure 4.4.2-4.

An overall airport methane loss schedule, shown in figure 4.4.2-5, was calculated for LAX to service the minimum loss aircraft. It was assumed that the airport liquid methane facility was a low loss system containing vacuum insulated liquid storage and distribution equipment. This schedule gives the capacity design requirement for a vent recovery system that could efficiently collect, and presumably dispose of, a vaporized gases flow that varied by at least a factor of five in a twenty four hour period.

If non-vacuum insulation were used for the airport liquid methane storage and distribution equipment, the losses would be significantly increased as shown in figure 4.4.2-6. The use of non-vacuum insulation is typical in the liquefied natural gas (LNG) industry. This industry, however, regasifies LNG for end use and is not overly concerned with liquid losses. The use of a lower grade insulation does reduce the peak and valley difference that must be handled by the vent gas recovery system. However, the merit of reducing these differences by increasing overall losses is questionable.

In terms of loaded aircraft fuel, the minimum liquid loss is approximately 3% of the fuel for a low loss vacuum insulated ground system and 5% for a non-vacuum insulated ground system. These losses are direct fuel price penalties unless they can be used to run airport equipment or the gas is purchased by a gas processor or utility. The Southern California Gas Company believes that they could handle the magnitude of vent gases estimated for LAX in a large trunk pipeline near the airport if it could be delivered at a pressure above 465 psig.[11] The price that would be paid for such gas would be dictated by current condition supply and demand. Washington Natural Gas could not handle the magnitude of vent gases estimated for Sea-Tac even considering their most optimistic customer growth schedule for the year 2000.[12] Even if market growth forecasts were grossly pessimistic, it would be essentially impossible to accept airport gas during the low summer season. In any case, vent gases must be pressurized from approximately one atmosphere to a pipeline acceptance or end use inlet pressure. This compression would reduce the availability of the vent gas by as much as 10%.

4.4.2.4 Costs

The cost of liquid methane is composed of the ***price*** of natural gas and the <u>cost</u> of all facilities required to: liquefy, store and deliver the fuel; safely capture and dispose of gases from vaporized liquid. Even if it is assumed that an acceptable delivered-to-airport liquid methane price can be negotiated, the on airport capital cost required for methane liquid and gas facilities will amount to more than 10¢ per equivalent gallon of jet A, as shown in figure 4.4.2-7. This low a capital cost assumes that Public or Utility financing can be obtained for airport conversion. A capital recovery factor of 0.12 was used for Public/Utility financing versus a recovery factor of 0.2 for commercial. Mixed inputs were received from various airport authorities as to the availability of low cost Public financing.

All ground equipment capital costs, as well as liquefaction facility costs, used in this study were based on customer acceptance of 100% of the facility rated output. Any drop in the requirement for fuel below this output will increase the price penalty per gallon. Therefore, costs, or prices, quoted for a non-petroleum based fuels are unrealistically low unless, like for petroleum, there is a ready market for this fuel during slack demand periods. In the case of conventional jet fuel, the facilities can be used to produce diesel or heating oil.

An important consideration in the development of airport facilities is the trade between the cost of liquid losses and the cost of equipment required to reduce these losses. This study did not include a cost trade that would allow a final design of the ground system, but a first cut analysis trading capital equipment requirements and losses was conducted using the Los Angeles airport as a model. Results of this trade, shown in figure 4.4.3-8, appear to be inconclusive with respect to a thermal protection system concept for methane. However, this trade did not account for active aircraft tank losses, aircraft/equipment cooldown, time losses associated with the cooldown of systems during relatively short periods of inactivity, or detanking. These studies must be conducted before a true airport cost can be assessed to the fuel or aircraft operations. It should also be strongly noted that: vented gases are a direct out of pocket cost to the airlines where capital costs may be wholly or partially paid by municipalities or governments.

Prices for liquid methane used in many transportation studies assume that the quoted price is for fuel delivered to the user. This would be true only if a liquid receiving terminal or liquefaction plant is located at the airport. If liquid must be transported from a terminal or liquefaction facility to an airport; the cost of transportation must be added to the fuel cost. The quantities of liquid associated with most airports considered for HSCT operations dictate the use of pipelines for any liquid delivery over land. In many areas of the world, permits for new large pipelines are difficult to obtain and even simple gas pipelines are expensive as shown in figure 4.4.2-9.

The cost of a pipeline for liquid methane (LNG) would be significantly higher than for natural gas, as shown in figure 4.4.2-10. A pipeline carrying a cryogen must be constructed of low temperature compatible materials, insulated and galleried, rather than buried (for safety and maintenance).

The loading of cryogens on an aircraft will require new and expensive equipment, relative to conventional fuels. In addition to provisions for filling the aircraft with liquid, a system must be provided to return vented gases to a recovery area. The density and insulation requirements for both methane and hydrogen require fill and vent lines that are too large for manual manipulation (maximum size for manual operation is equivalent to 4" rubber hose). Several promising concepts have been proposed for loading a cryogen on an aircraft, such as the one compared with the manual system in figure 4.4.2-11[13]. None of these concepts have been subjected to a safety analysis or have addressed the operational problems associated with accounting for the quantity of gas vented as well as liquid delivered. In an age where airlines compete on a vary slim profit margin, they will insist that fuel management include credit for vaporized liquid as well as a debit for liquid delivered.

As with conventional fuels, Task 3 results were used as support data in establishing methane prices to be used by all participants in the NASA study. In addition, data from Tasks 4 and 7 were used to establish the on-airport prices for methane shown in figure 4.4.2-12. These prices were based on the assumption that the user would be able to sign a long term contract for a fixed quantity of product. Liquid methane — for that matter its raw material natural gas — is a perishable commodity. The validity of the assumption that aircraft users will be able to sign long term liquid methane contracts or will receive the product at the —To Airport— cost level could not be verified.

4.4.2.5 Recommendations

When cryogen ***prices*** are compared with the ***price*** of kerosene type fuels the comparison should include:

- the effects of variations in aircraft demand on system size and losses;
- identification of other users that can insure that their is a real second market for the output of production facilities — such data must cover a realistic range of facility sizes and airport locations;
- identification of a segment of society that is willing to invest in and supply the fuel at the price assumed in the study.

4.4.3 OTHER FUELS

Fuels other than liquid methane and modified conventional fuels were evaluated and reported in Task 3.[2] Only key points are reported in the following sections.

4.4.3.1 Endothermic Fuels

No data were uncovered that indicated promise for the development of an endothermic fuel that would satisfy commercial HSCT requirements. The most promising fuel still appears to be methylcyclohexane. Its heat absorption capability is marginal in the operating pressure and temperature regime found in acceptable designs of an HSCT fuel system (figure 4.4.3-1).

4.4.3.2 Slushes

Problems associated with the use of slushes, such as below ambient pressure or inert gas storage, still appear to be more formidable than the problems they solve.

4.4.3.3 Gels

No investigation was conducted.

4.4.3.4 Recommendations

No further work on other fuels is suggested.

4.5.0 CONCLUSIONS & RECOMMENDATIONS

The most significant conclusions and recommendations developed in this study are summarized in figure 4.5.0-1.

The viability of any fuel chosen for a commercial aircraft is directly related to price and price is strongly influenced by supply and demand. No supplier is going to make a major investment in a new product unless the profit incentive (price minus cost) is worth the risk. There is little chance that this condition can be satisfied for fuel with only one user, for example: aircraft. Therefore, there is at least as high a market driven as technical risk associated with the use of new or different fuels for civil transports, as reflected in the key risk items shown for the Task 4 & 7 study fuels in figure 4.5.0-2.

4.6 REFERENCES

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4 Earls. J. W. (Shell International Trading Co.) Kendall, D. R. and Clark, R. H. (Shell Research Ltd., "Experimental Studies of Aviation Fuel Thermal Stability: A Recent Case Study," Paper presented at the 27th IATA Aviation Fuels Subcommittee, Geneva, September 15 & 16th, 1987.

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7 Haley, Kenneth, "Changes in Transportation Fuels Seen as a Major Trend in Refining", Hydrocarbon Processing, May 1987, page 15.

8 Editors, 27th Meeting of the IATA Aviation Fuel Sub-Committee, Geneva, 15/16 September 1987, Report AFSC/27 - Item 4(b).

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10 R. W. Niedzwiecki,"High Speed Fuels Workshop," Presentation prepared for AAC/ARTS High Speed Transport Ad — Hoc Review Team, NASA Headquarters, November 19, 1987.

11 Telecon, Southern California Gas Company, Production/Distribution Department (2/8/88).

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13 Boeing, "An Exploratory Study to Determine the Integrated Technological Air Transportation System Ground Requirements of Liquid-Hydrogen-Fueled Subsonic Long-Haul Civil Air Transports," NASA CR-2699 (9/76).

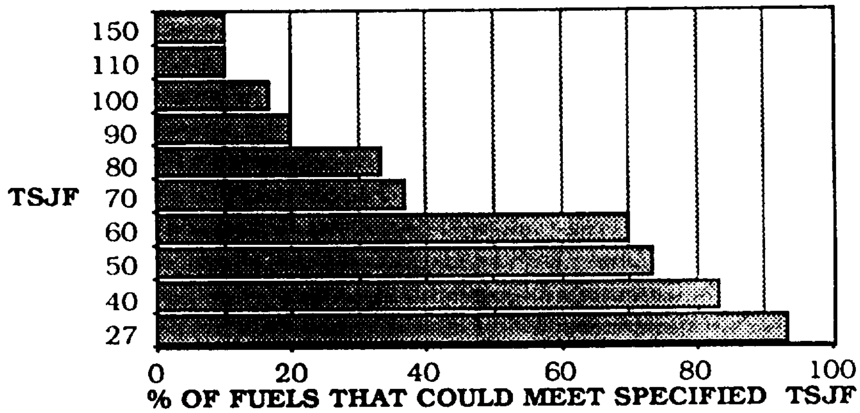


Figure 4.1.0-1 Thermal Stability of Currently Delivered Fuels

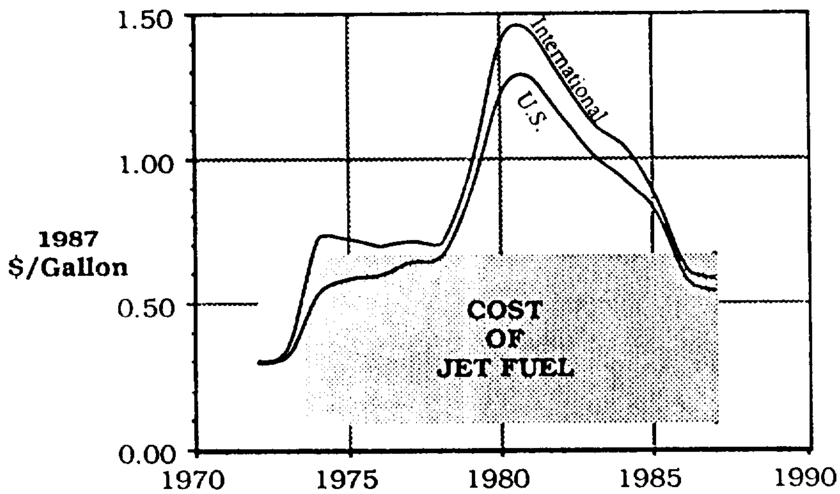


Figure 4.1.0-2 Cost Versus Price of Jet Fuel

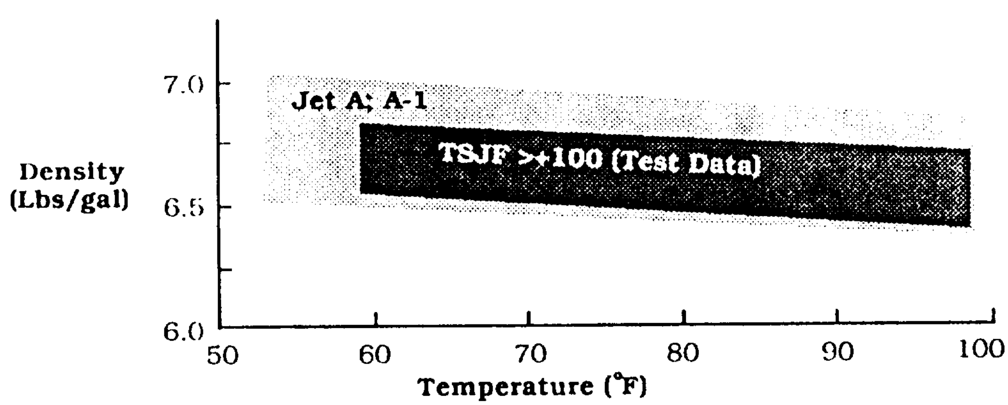


Figure 4.1.0-3 Density of high thermal stability fuels

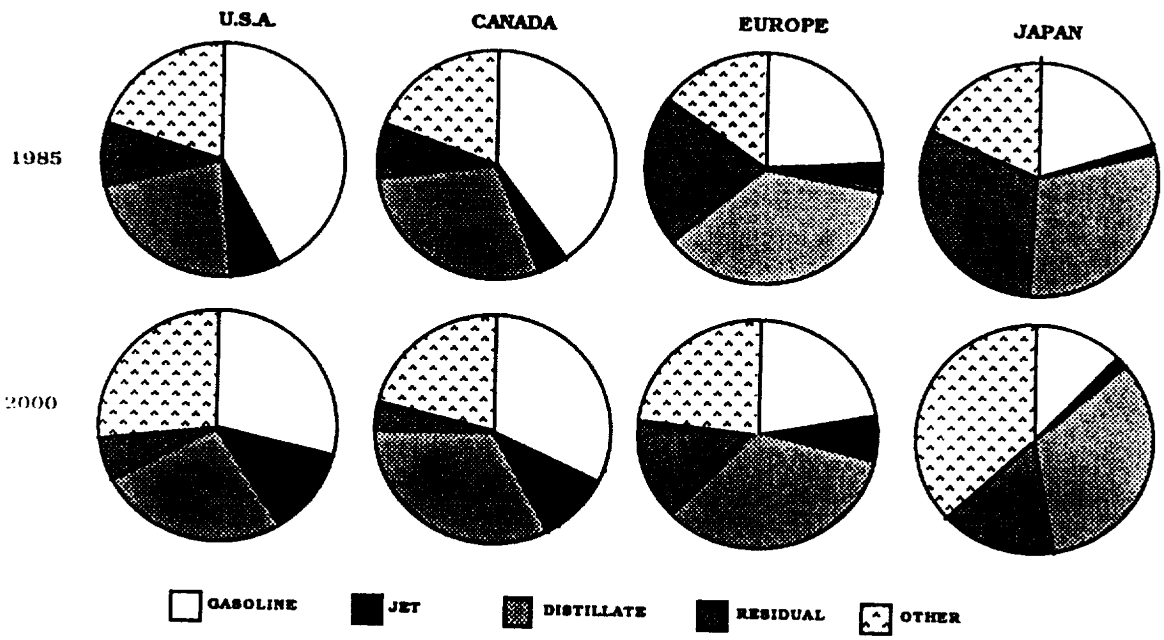


Figure 4.1.0-4 Worldwide Product Demand Change

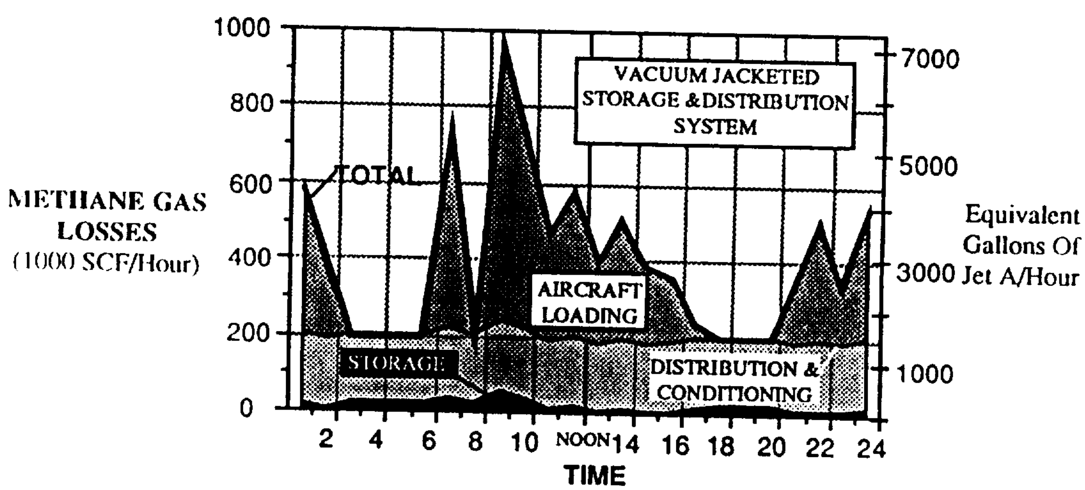


Figure4.1.0-5 Airport Losses (LAX)

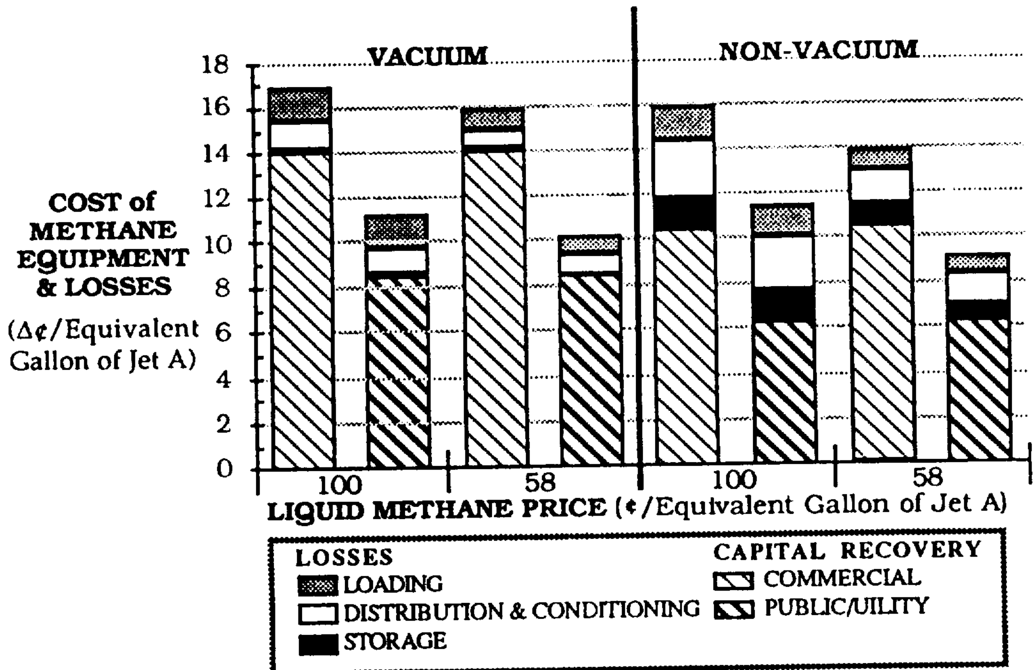


Figure 4.1.0-6 Liquid Methane Airport Conversion Costs (LAX)

	PRICE Equivalent Gallons of Jet A	
	02/04/88 (to airplane) Range	Reference
Jet A	50¢ to 75¢	60¢
Thermally Stable Jet Fuel		
TSJF + 50	50¢ to 85¢	62¢
TSJF +100	60¢ to 95¢	71¢
TSJF +150	70¢ - $1.10	92.5¢
Liquid Methane/LNG	50¢ to $1.00	
Demand (Tons/Day)		
>7,000		68¢
2,000		73¢
500		83¢

Figure 4.1.0-7 Study Fuel Prices

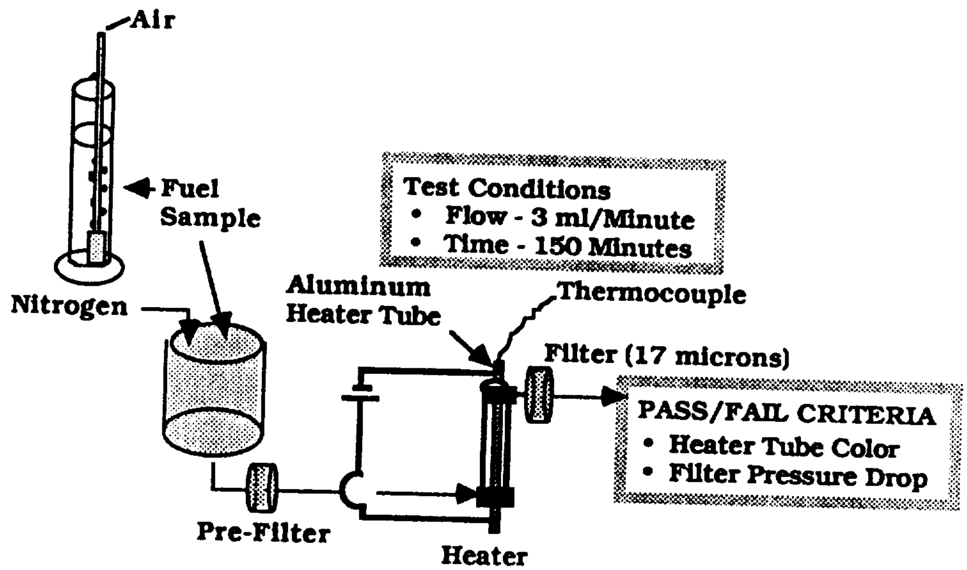


Figure 4.4.1-1 Jet Fuel Thermal Oxidation Tester (JFTOT)

- TSJF +0 Means that:
  - A fuel passed the ASTM Jet A JFTOT minimum of 245 °C (473 °F)
- TSJF +50 (or + x) Means that:
  - The fuel passed the JFTOT ≥ 50 °F (or + ≥ ° x) higher than 245 °C (≥523°F)
- The 260 °C IATA Jet A-1 minimum JFOT = TSJF +27

Figure 4.4.1-2 TSJF Definition

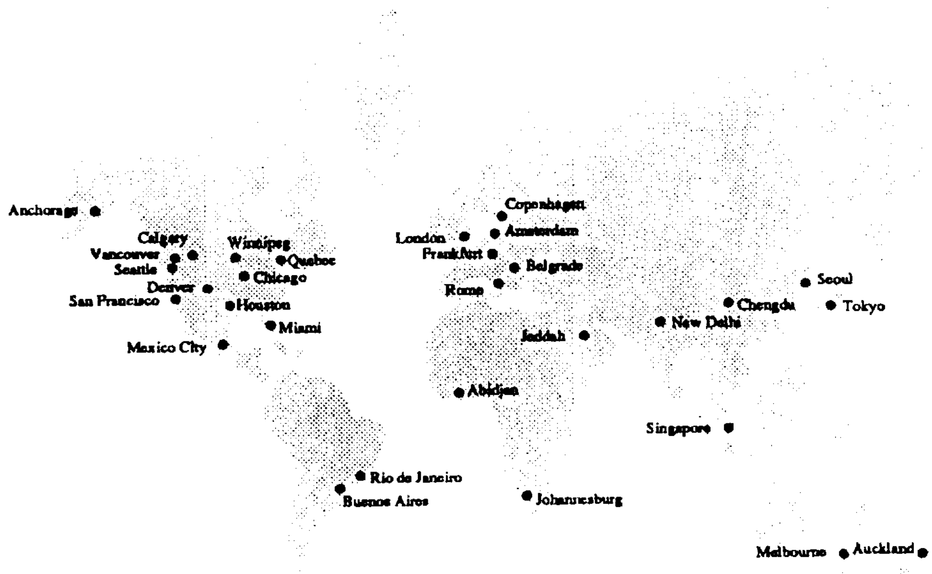


Figure 4.4.1-3 Airport Sample Locations

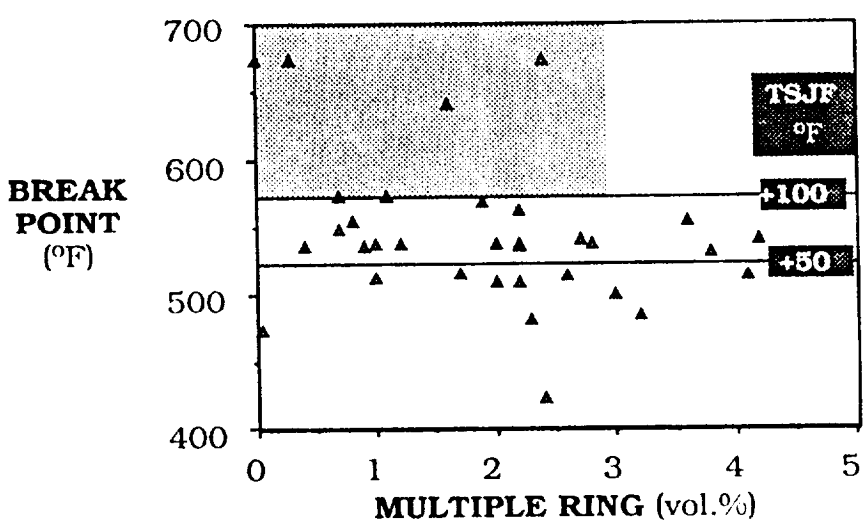


Figure 4.4.1-4 Aromatic Effects

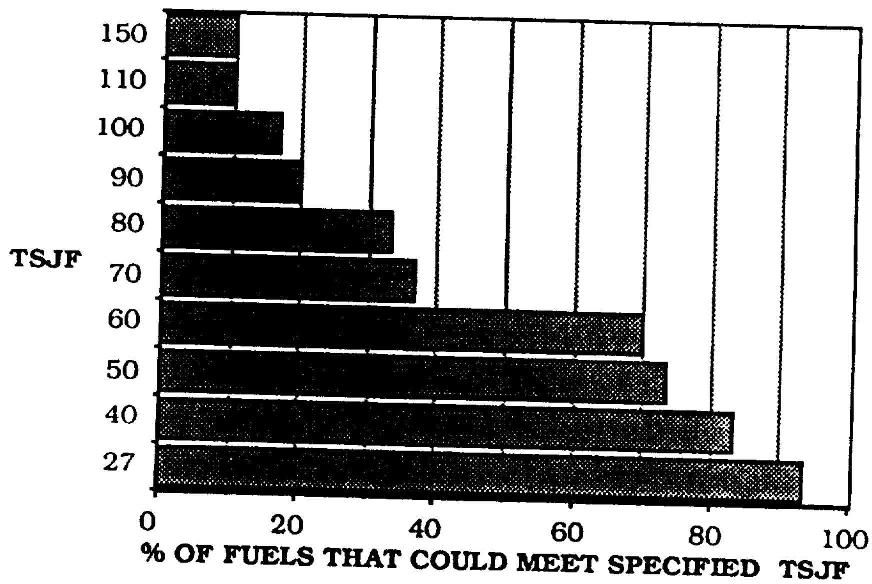


Figure 4.4.1-5 Thermal Stability of Currently Delivered Fuels

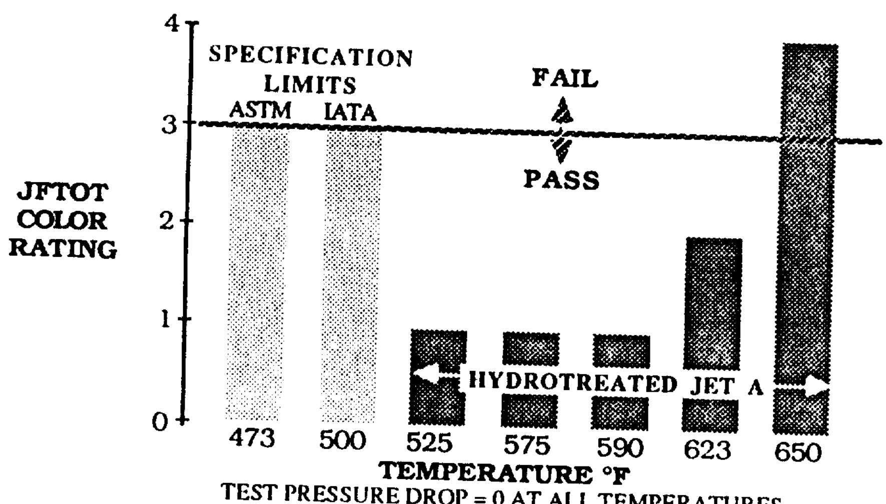


Figure 4.4.1-6 Thermal Stability of Hydrotreated Jet A

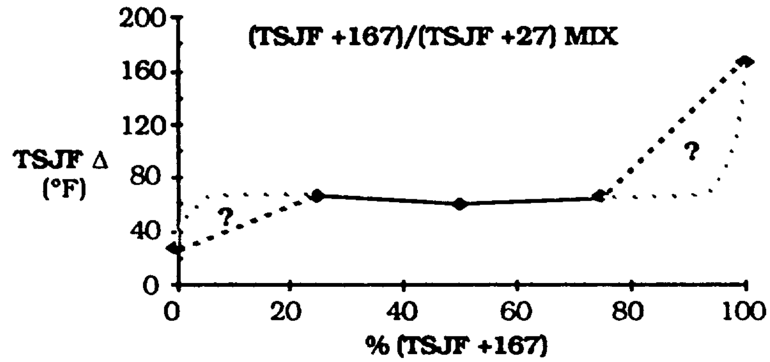


Figure 4.4.1-7 Mixing Effects

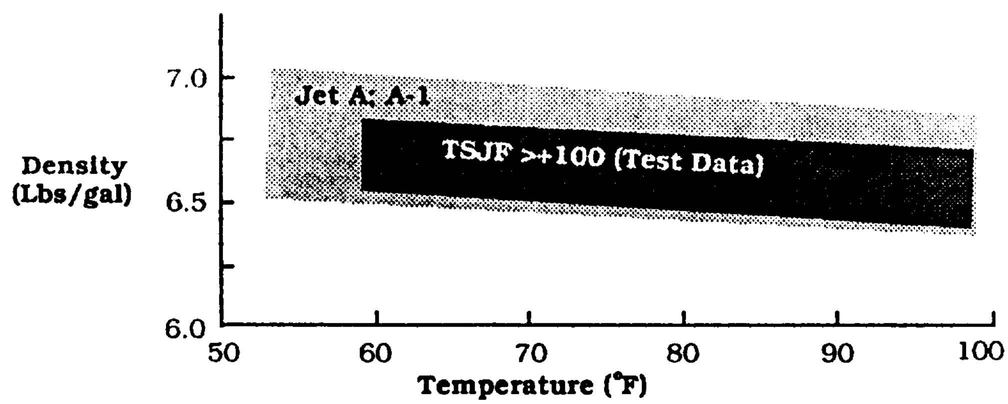


Figure 4.4.1-8 Density of high thermal stability fuels

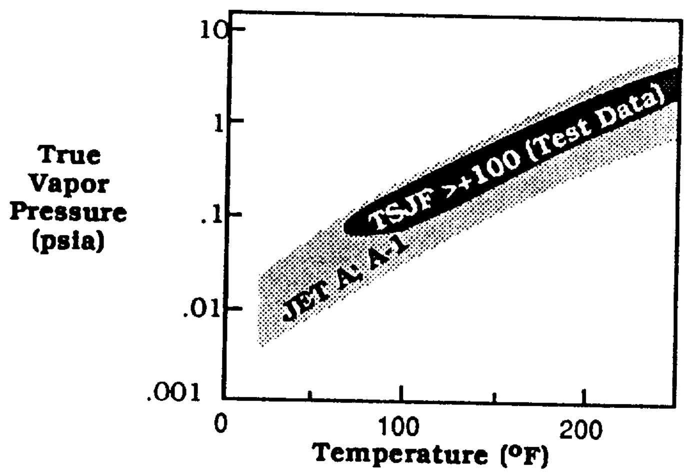


Figure 4.4.1-9 Vapor Pressure of high thermal stability fuels

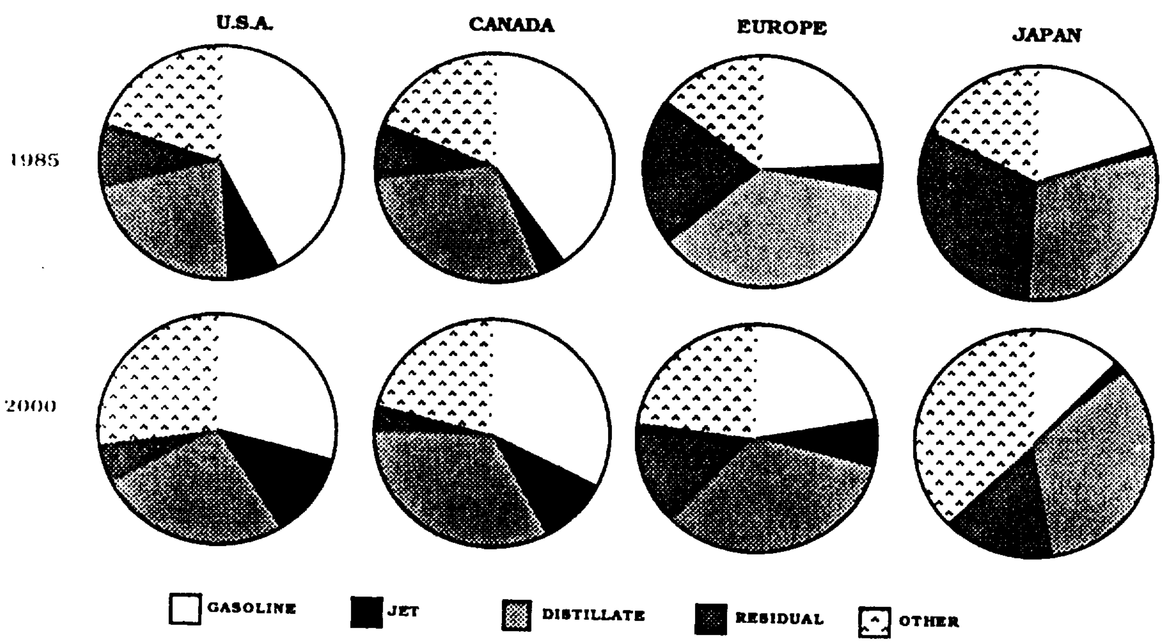


Figure 4.4.1-10 Petroleum Product Market Share

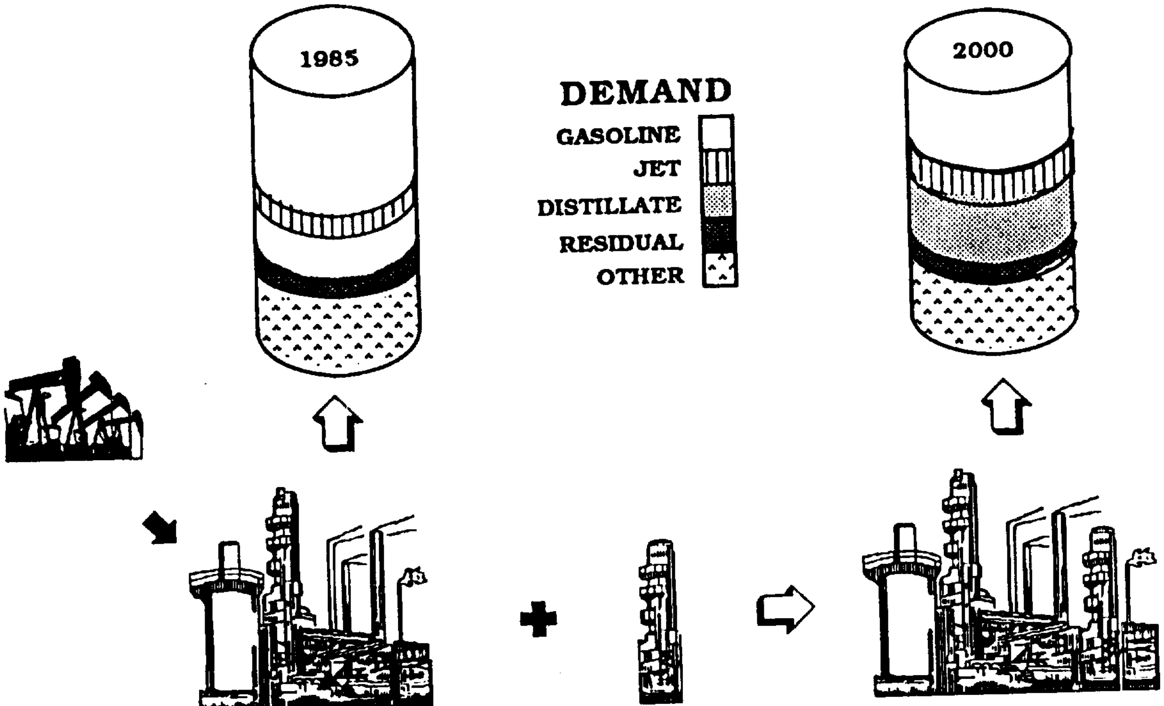


Figure 4.4.1-11 Refinery Upgrade Requirement

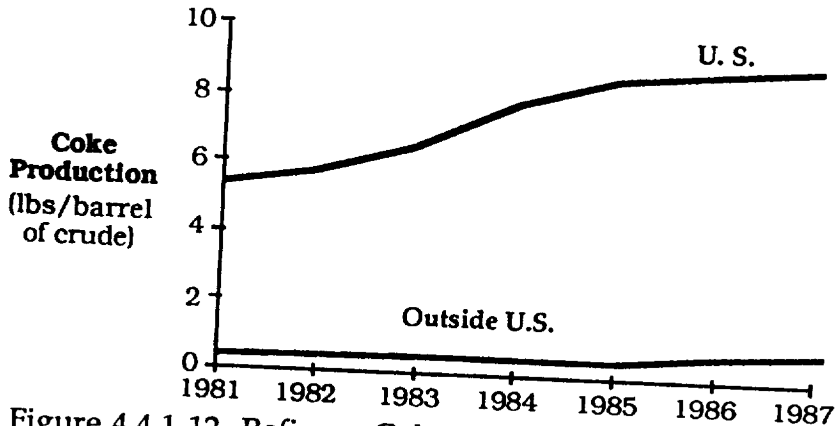


Figure 4.4.1-12 Refinery Coke Production

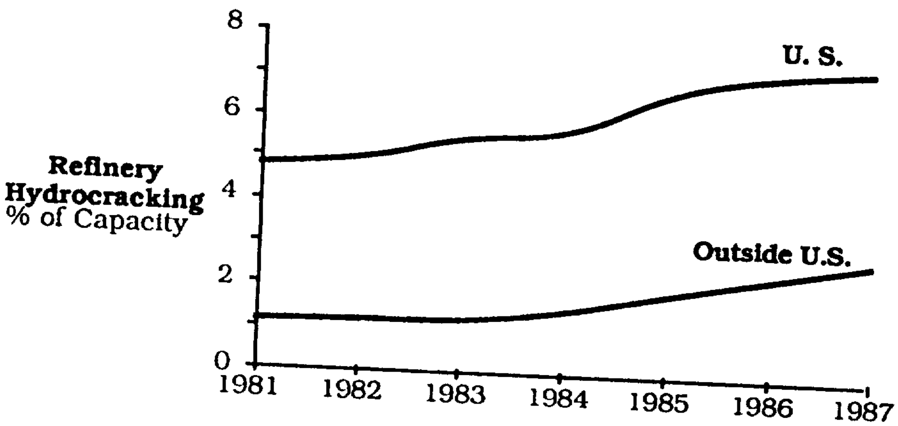


Figure 4.4.1-13 Refinery Hydrocracking Capacity

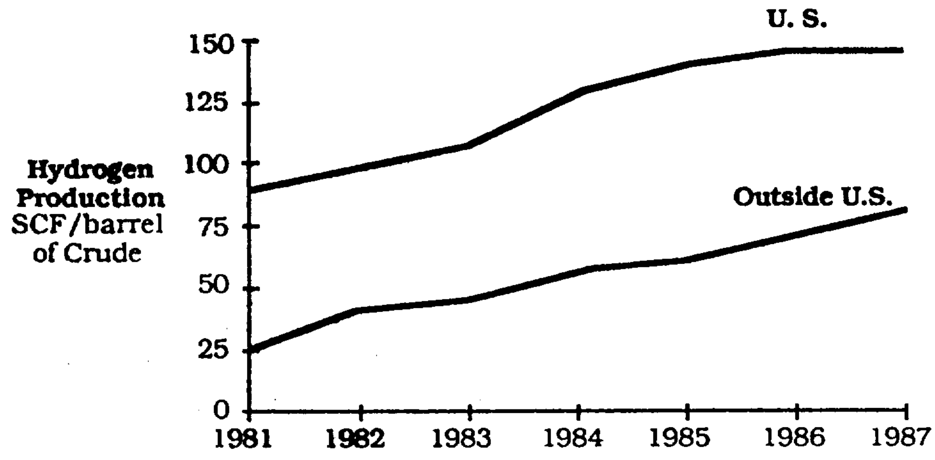


Figure 4.4.1-14 Refinery Hydrogen Production

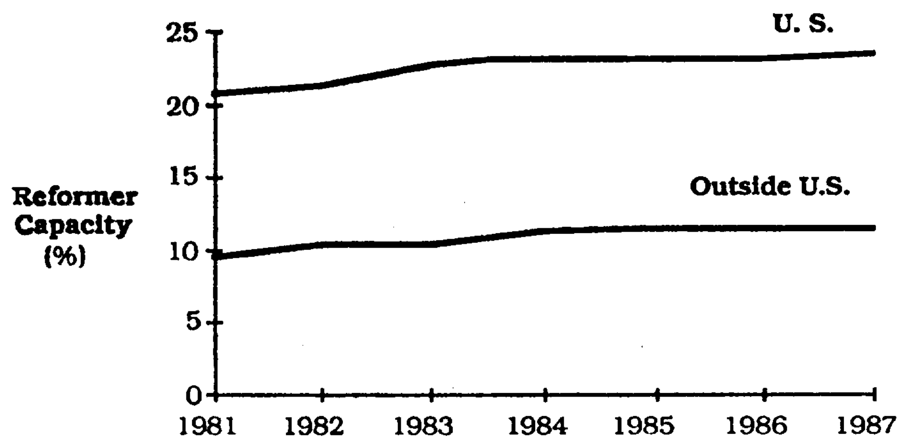


Figure 4.4.1-15 Refinery Reformer Capacity

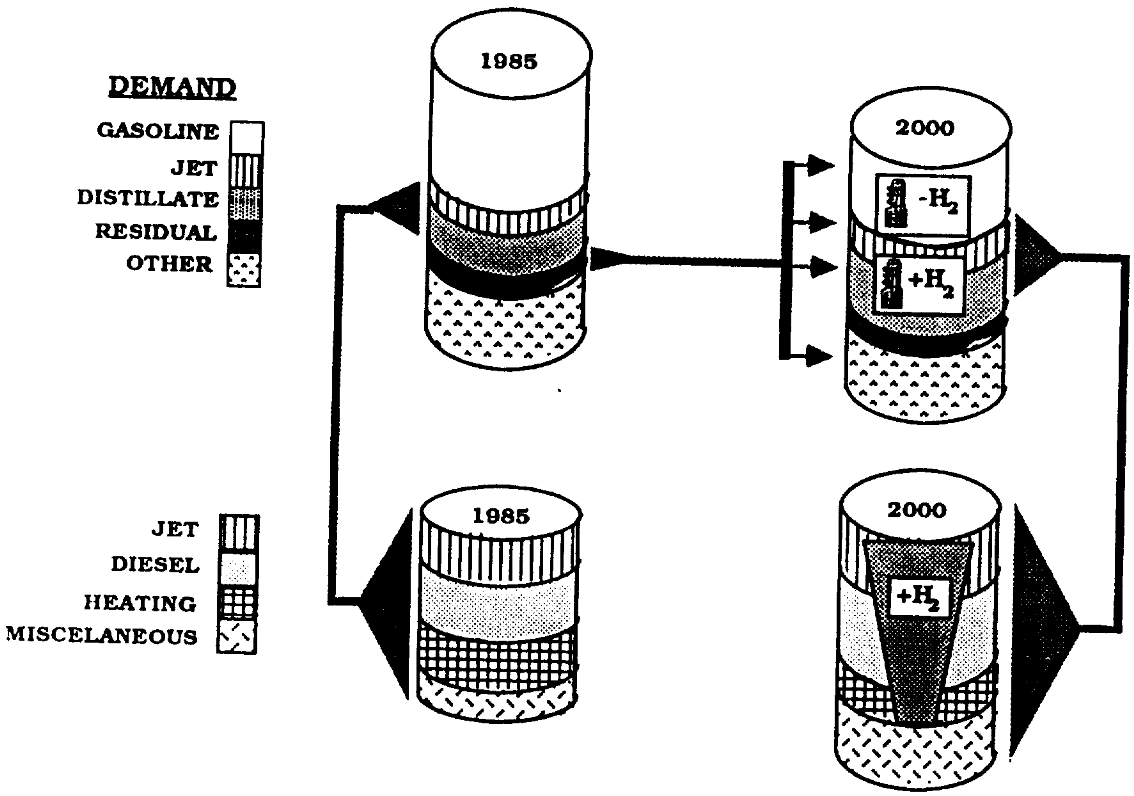


Figure4.4.1-16 Refinery Reformer Capacity

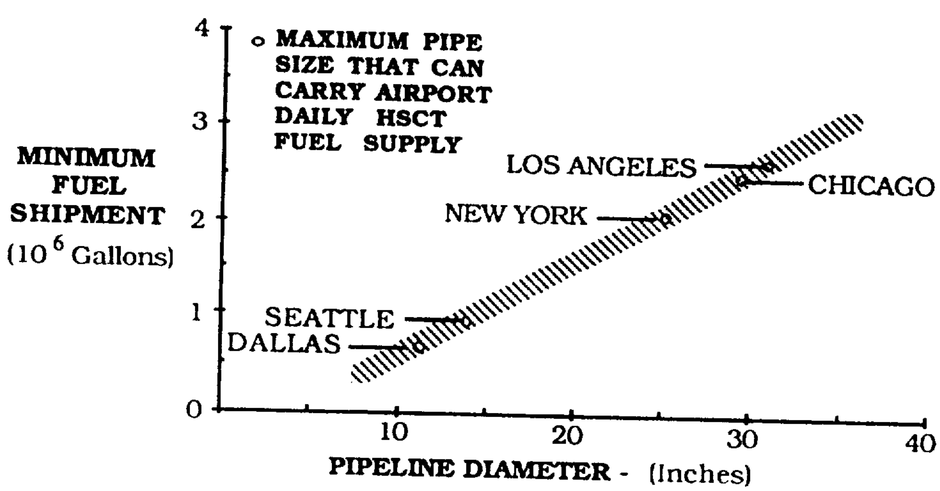


Figure 4.4.1-17 Pipeline Fuel Shipment

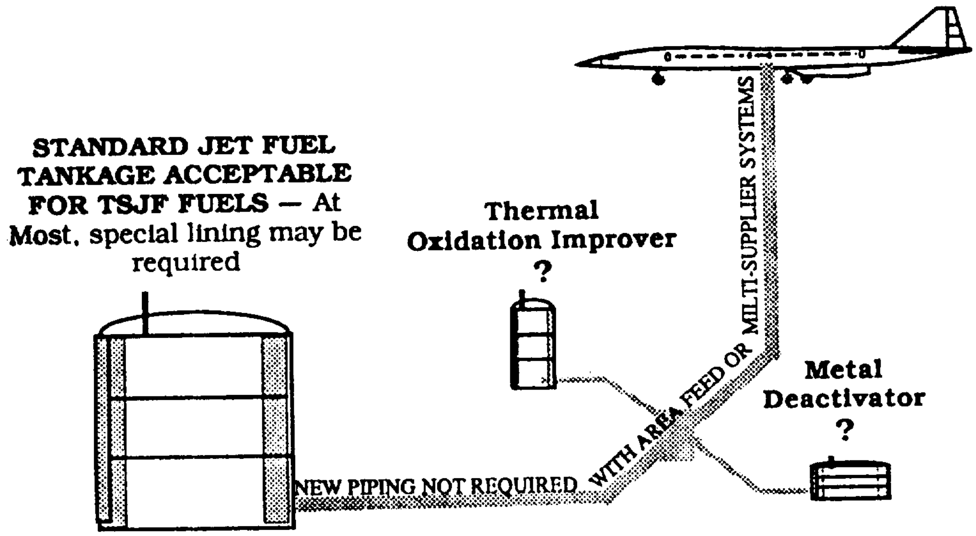


Figure 4.4.1-18 Thermally Stable Jet Fuel Airport Requirements

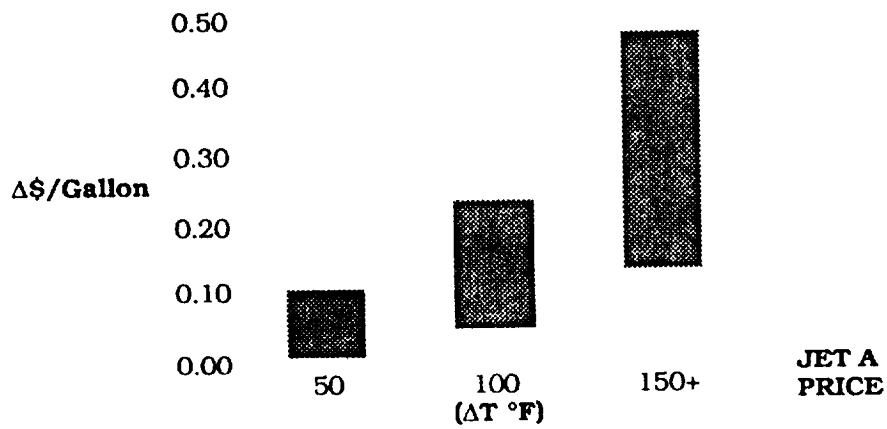


Figure 4.4.1-19 Cost Estimate for Thermal Stability Improvement

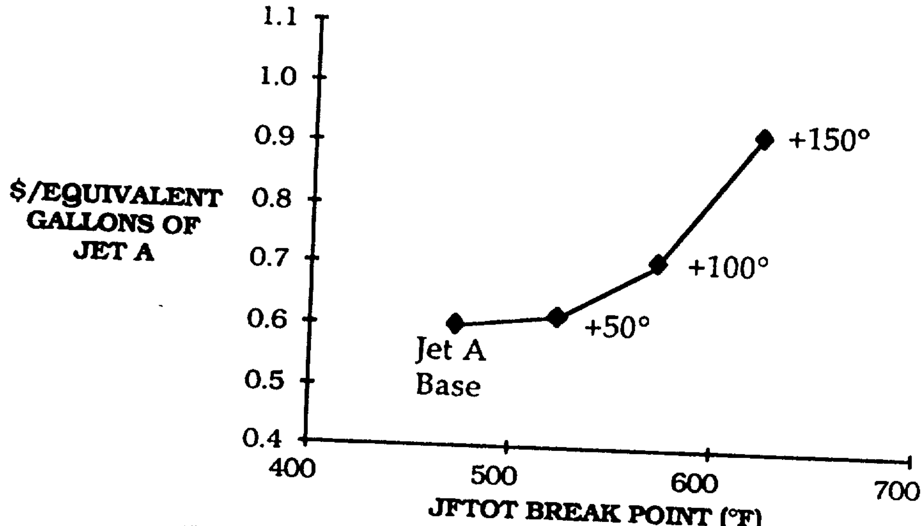


Figure 4.4.1-20 NASA Study Fuel Prices

	COST — ¢/Gallon
Crude Oil (50¢ to 20$ per Barrel)	1.2 to 48
Capital + Operations	7.7 to 14
Delivery	<5
TOTAL AT AIRPORT	**9 to 67**

Figure 4.4.1-21 Cost of Jet Fuel

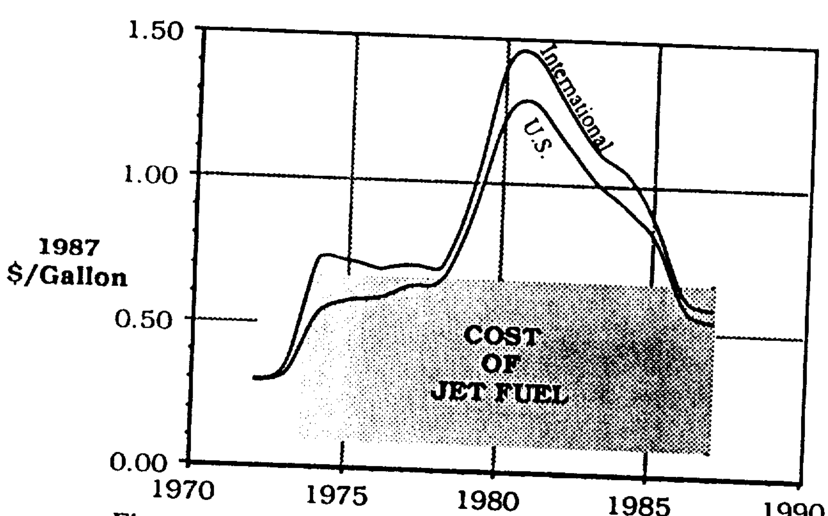


Figure 4.4.1-22 Cost Versus Price of Jet Fuel

Modification	Possible Benefit
Standardize initial fuel temperature	Provide common reference
Bake fuel prior to test	Simulate heating in HSCT wing tank
Increase fuel flow rate	Induce turbulence
Recycle fuel	Allow for longer term heating effects; Maintain small sample size
Reduce heater power	More realistic heating environment
Maintain constant heater power or maintain constant temperature and measure heater power	Provide indication of lacquering
Monitor outlet fuel temperature	Observe changes in heat flux
Control temperature environment	Minimize uncontrolled temperature variations

Figure 4.4.1-23 Suggested JFTOT Modifications

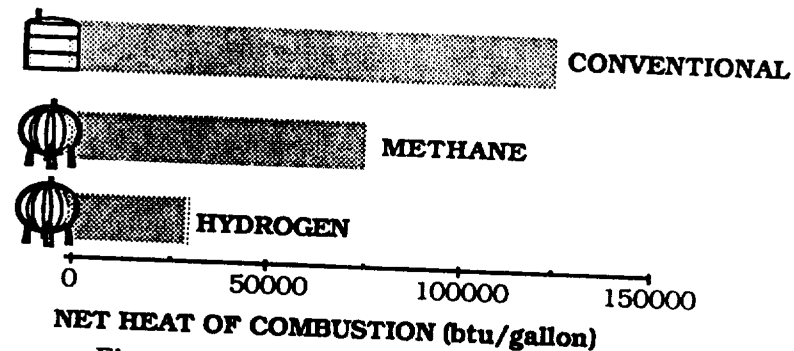


Figure 4.4.2-1 Volumetric Energy Content

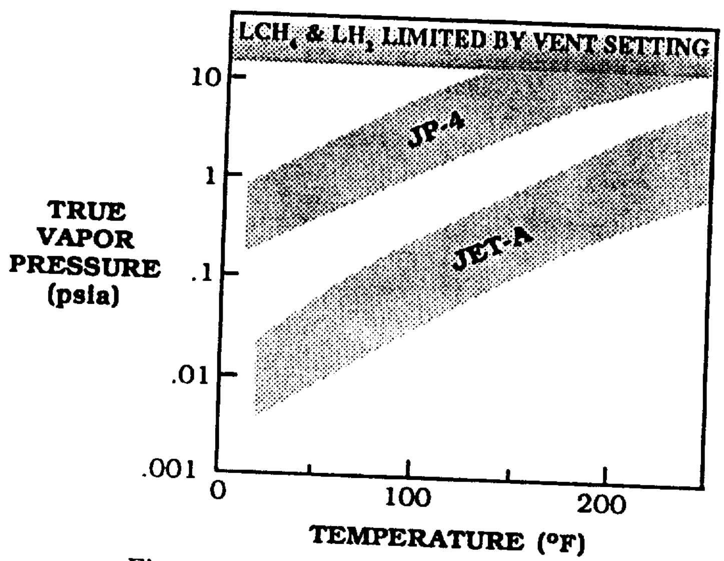


Figure 4.4.2-2 Fuel Storage Pressures

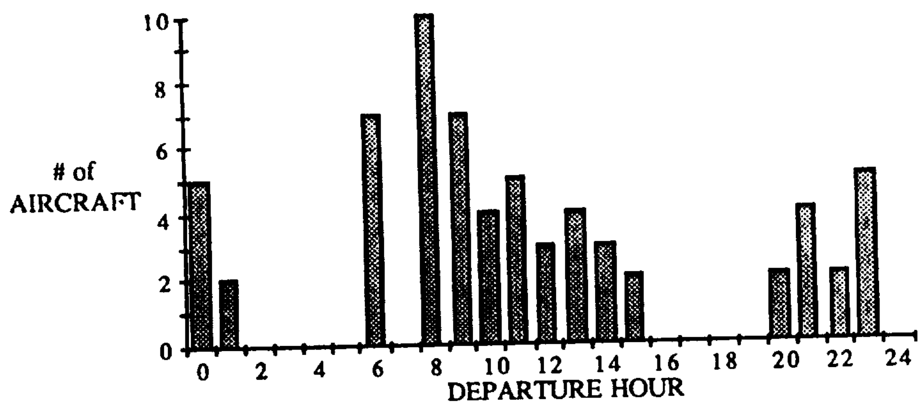


Figure 4.4.2-3 HSCT Departures — LAX

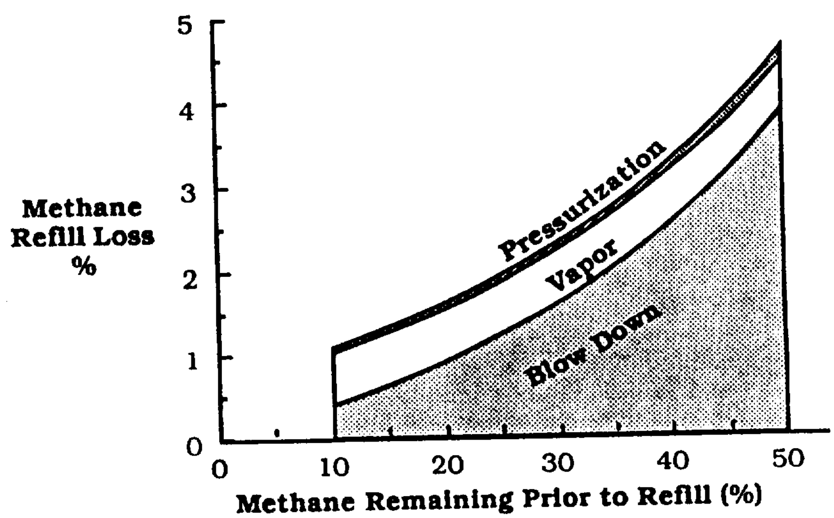


Figure 4.4.2-4 Aircraft Loading Losses

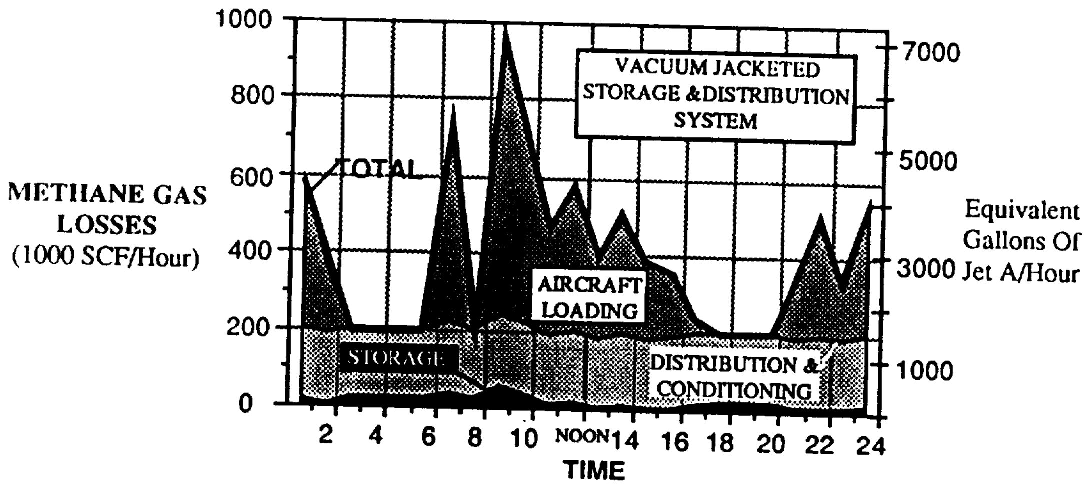
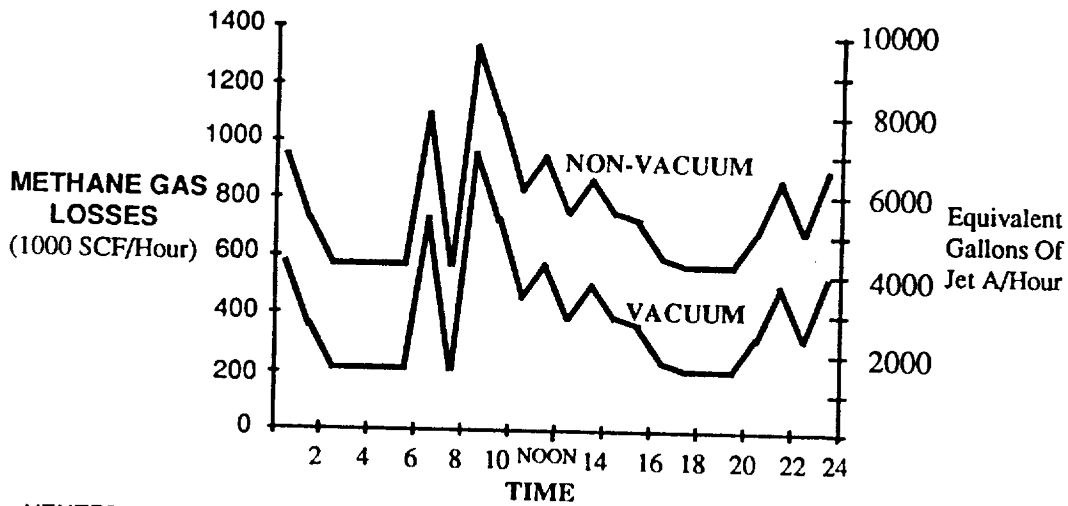


Figure 4.4.2-5 Airport Losses



- VENTED GAS = 9.7 Million SCF/Day = 69,600 Equivalent Gallons of Jet A/Day (Vacuum)
  18.5 Million SCF/Day = 132,900 Equivalent Gallons of Jet A/Day (Non-Vacuum)
- LOADED FUEL = 2.6 Million Equivalent Gallons of Jet A/Day

Figure 4.4.2-6 Methane Gas Losses

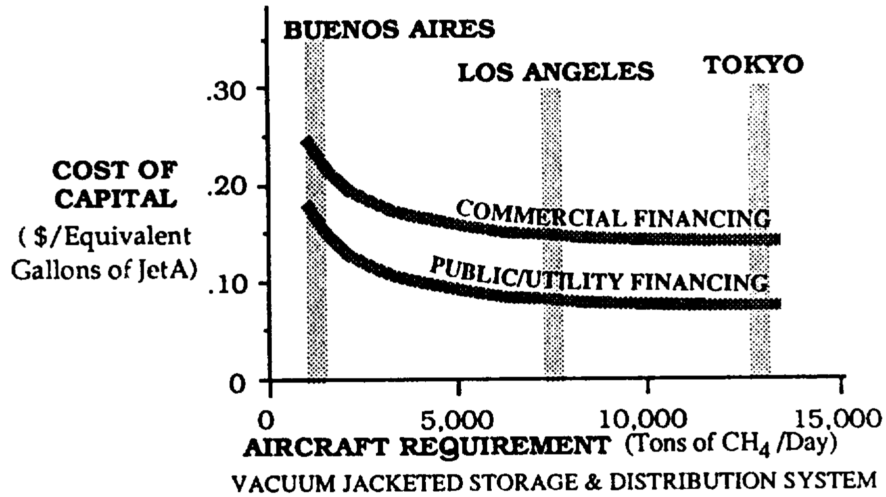


Figure 4.4.2-7 Airport Conversion Costs

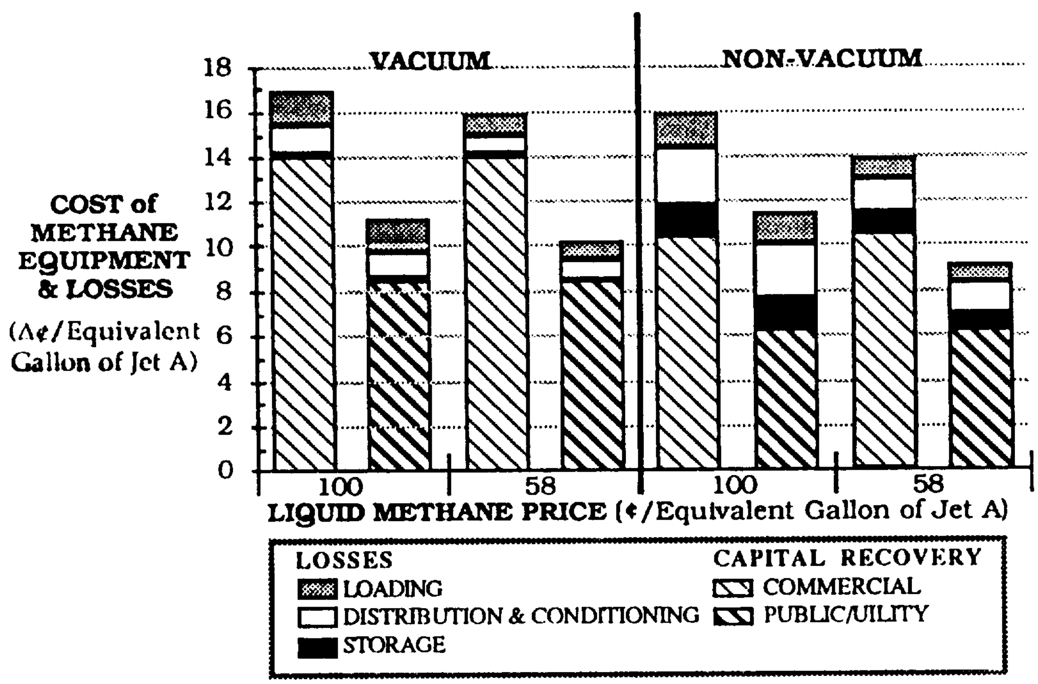


Figure 4.4.2-8 Liquid Methane Airport Conversion Costs

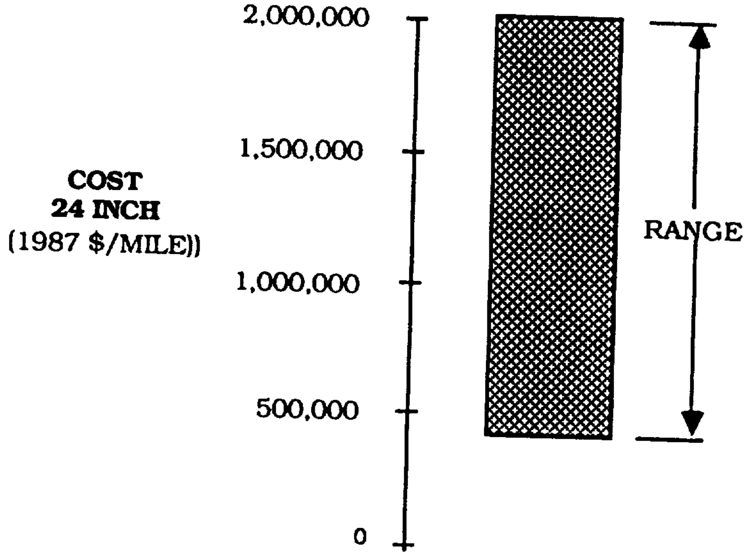


Figure 4.4.2-9 Natural Gas Pipeline Cost

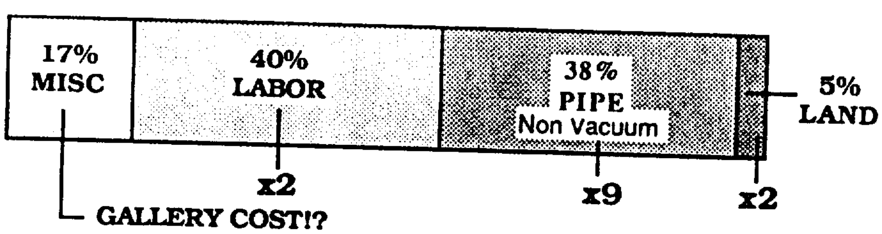


Figure 4.4.2-10 Cost Increase Factors for LNG Pipeline

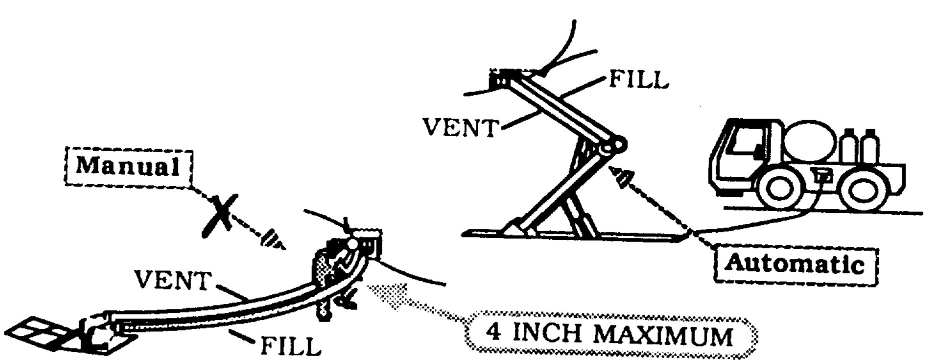


Figure 4.4.2-11 Cryogenic Fuel Loading Concept

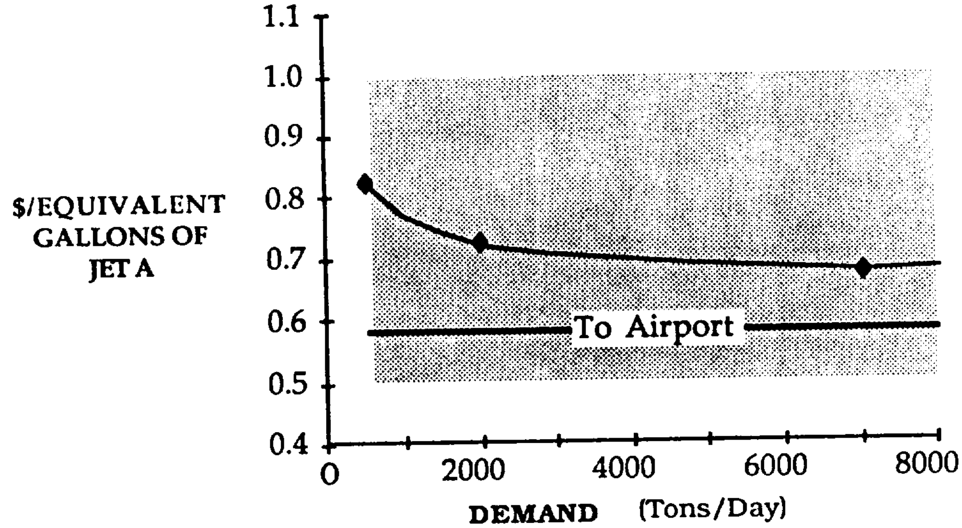


Figure 4.4.2-12 Liquid Methane Study Prices

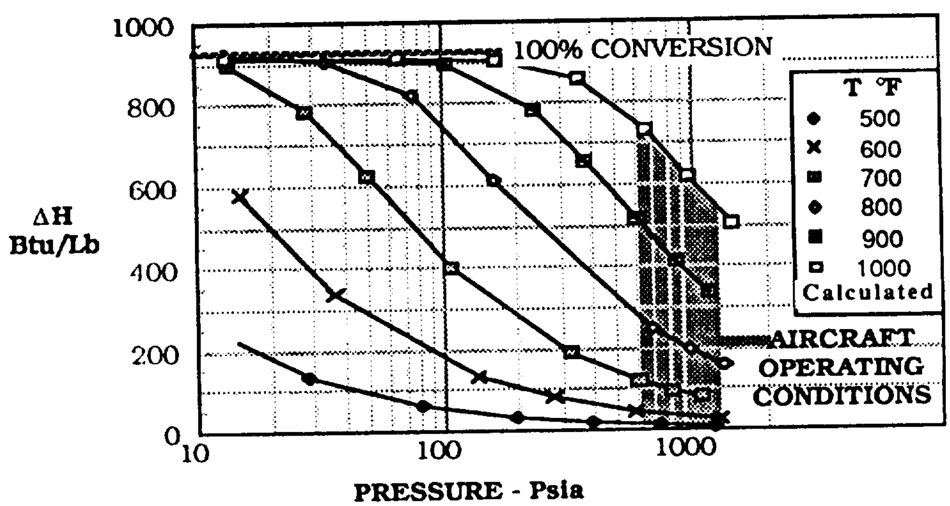


Figure 4.4.3-1 Methylcyclohexane - Reaction Heat Absorption

FUEL	CONCLUSIONS	RECOMMENDATIONS
Modified Conventional	Jet fuels currently delivered to airports do have higher than required thermal stabilities – >60% adequate for up to Mach 2.8 aircraft Extended temperature tolerance is possible with little or no cost penalty High thermal stabilities can be maintained without special handling Trace metal content of jet fuels and their effects are not known	Establish data base for high thermal stability fuels. Develop improved stability test and/or aircraft/engine simulator Determine trace metal content of jet fuels and assess possible effect on environment
Liquid Methane	Prices have not been developed on a compatible base with conventional fuels	Consider all losses and effects of demand variations on price before comparing with kerosene based fuels.

Figure 4.5.0-1 Conclusions & Recommendations

FUEL	RISK
Methane/LNG	Price will be dictated by seller if airlines are only user. Local conditions have large impact on supply and price of raw material. No existing infrastructure for supplying fuel and no capital risk takers have been identified. Environmental impact and safety associated roadblocks could stop development of fuel supply at any time.
TSJF +50	Small price penalty if not required for subsonic aircraft.
TSJF +100	Small price penalty for additives and special handling. Significant price penalty if middle distillate demand is in balance with middle distillate production capacity — condition only expected if Third World fuel demand increases dramatically .
TSJF +150	Price penalty will be dictated by competition for low sulfur middle distillates — added cost for refinery upgrading may be necessary to support HSCT supply requirements. Airport fuel storage and distribution system upgrade may be required.

Figure 4.5.0-2 Conclusions & Recommendations

5.0 AIRPORT CONGESTION STUDIES

5.1 INTRODUCTION

The addition of an airplane with different performance and wake turbulence characteristics can have a strong influence on airplane throughput at an airport. Due to the rapid increase in airport congestion and delay, this has become a sensitive issue at all major airports around the world. This study takes a look at some of the key parameters to determine their influence on airplane throughput at a typical airport. The airport used in the analysis is Seattle-Tacoma International which has configuration and operational characteristics which are similar to other major airports.

5.2 STUDY ASSUMPTIONS

The measure used to judge the results of the analysis is airplane throughput, which is the maximum combined number of airplane arrivals and departures achieved in a one hour period. Throughput estimates were made using a fast time simulation of the airport environment. The simulation examines the air side operations at the airport. Arrival simulation starts with the airplane approaching from either the outer marker or turn-on to final approach and ends with the airplane exiting the runway. Departure simulation starts with the airplane entering the runway, ending when the airplane is into its initial climb.

The typical operating procedure at an airport is for airplanes to be turned on to final approach at varying distances from the threshold. In the baseline simulations it has been assumed that the common path length, shared by all airplanes, is the final approach distance of 5 NM. Sensitivity of throughput to the common path distance variation has been simulated by increasing the common approach distance up to 15 NM.

The airport chosen for the analysis is Seattle-Tacoma International Airport (SEA) which has a two runway configuration. The two runways, which are 9425 ft and 11900 ft long, are parallel and spaced 700 ft apart. This is a configuration which is identical to half of Los Angeles and Atlanta, and similar to London-Heathrow. The results should provide a qualitative indication of the change in airplane throughput which may be expected at other airports designed to different configurations.

The runway use at SEA is dependent on the operating conditions. In VFR conditions each runway may be used independently for arrivals. Departures are constrained so that, effectively, only one runway is used. In IFR conditions, the operating constraints effectively force one runway to be used for arrivals and the other for departures.

A simplification to the problem of multiple airplane types is achieved by grouping airplanes into one of four classes. The classes are as follows;

Class 1	HSCT airplanes
Class 2	Jets with MTOGW greater than or equal to 300,000 lb.
Class 3	Jets with MTOGW less than 300,000 lb.
Class 4	All propeller airplanes.

The Class 2 and 3 airplanes are usually referred to as heavy jets and large jets, respectively.

Estimates of airplane throughput at SEA have been made for both VFR and IFR conditions. The difference between these operations is in the arrival-arrival spacing. The baseline HSCT airplane is assumed to have wake turbulence characteristics similar to a Class 2 or heavy jet, and hence, the arrival-arrival spacings for airplanes following an HSCT will be the same as for those following a Class 2 airplane. These spacings are given in Table 5.2-1.

The current SEA airplane mix has been assumed as the baseline for the study. The scheduled airplane mix has been extracted from OAG tapes and the unscheduled airplane mix has been estimated from airplane strip counts at similar airports. SEA has less than 7 percent of unscheduled traffic, so that the unscheduled traffic has a minimal effect on the overall airplane mix. When HSCT airplanes are added to the traffic, then the percent of each airplane class are reduced proportionally. The current airplane mix at SEATAC is as follows;

Class 1	0.0%
Class 2	10.5%
Class 3	49.8%
Class 4	39.7%

In a number of cases, throughput results are shown for either a 50/50 split of arrivals and departures or for arrivals only. The reason is that it is normal to expect an equal number of arrivals and departures over a period of time, however, this does not always occur within a short time span. With banking at hub airports, it is common for either arrivals or departures to be clustered. Also, airports with parallel runways spaced over 2500 ft apart are able to operate independent arrivals and departures. There are several airports that have parallel runways spaced at least this distance apart, for instance; Honolulu (6630 ft), Houston (5700 ft), Miami (5000 ft), NY-Kennedy (3000 ft and 6700 ft), London-Heathrow (4500 ft), Paris-Charles de Gaulle (9760 ft) and Rome-Fiumicino (12400 ft)

5.3 STUDY RESULTS

The parameters examined in the study are as follows;

Approach speed,
Proportion of HSCT airplanes,
Proportion of arrival airplanes in the operations mix,
Wake turbulence spacing, and
Common approach path length.

5.3.1 APPROACH SPEED and PROPORTION OF HSCT AIRPLANES

An assumption made in the approach speed analysis was that departure speed was not changed. It is reasonable to assume that any variation in airplane design which would cause the approach speed to be increased would also require that climb-out speed also be increased. However, it was decided to ignore changes to the climb-out speed for two reasons. First, it was not known how climb-out speed would vary with approach speed, and secondly, including a change in climb-out speed would tend to mask the effects of approach speed. Rather than change two variables at the same time, it was decided to maintain a constant climb-out speed.

The spacing between arrival airplanes is governed by the greater of the wake turbulence spacing or the runway occupancy time. Runway occupancy being defined as the time required from runway threshold crossing to runway exiting. As HSCT approach speed is increased two opposing trends occur; the time required to travel the wake turbulence spacing distance is reduced, and runway deceleration distance is increased which increases the runway occupancy time. These contrary effects are displayed in Figures 5.3.1-1, -2 where the effects of HSCT approach speed and the percentage of HSCT airplanes in the airplane mix are examined.

Consider the case of arrivals only, no departures, in Figure 5.3.1-1. In VFR conditions where arrival spacing varies from 1.9 NM to 3.6 NM, approach speed increase has a detrimental effect on airplane throughput. This is due to the HSCT runway occupancy time being dominant. In fact, at 185 knots approach speed, the throughput can be seen to fall off rapidly. As approach speed is increased from 175 to 185 knots, the HSCT is unable to slow down for the third exit and has to coast on to the last exit.

In IFR conditions, where arrival spacing increases to a range of 3.0 NM to 5.0 NM, increasing HSCT approach speed does improve airplane throughput. This improvement is due to the reduction in the time required to travel the fixed separation distance, which is now the dominant variable.

However in both VFR and IFR conditions, changing the proportion of HSCT's in the airplane mix has a larger impact on the airplane throughput than changing the HSCT approach speed. With an HSCT approach speed of 145 knots, this is equivalent to adding more Class 2 airplanes which require a larger spacing for the trailing airplanes.

When a 50/50 mix of arrivals and departures are simulated, arrivals and departures tend to be interleaved, Figure 5.3.1-2. In VFR conditions, a small increase in the spacing between arrivals will permit the insertion of a departure. This increase in arrival spacing means that the increase in HSCT approach speed is effectively masked, and that for the range of approach speeds considered, has no effect on the airplane throughput.

In IFR conditions, arrival-arrival spacing time is still the dominant variable and throughput is increased as HSCT approach speed is increased.

As in the arrivals only case, changing the proportion of HSCT's in the airplane mix has a larger impact on the airplane throughput.

5.3.2 PROPORTION OF ARRIVALS

The effect of varying the proportion of arrival airplanes is examined in Figures 5.3.2-1 through 5.3.2-4. Figures 5.3.2-1 and 5.3.2-2show throughput versus approach speed and proportion of arrivals, for 10 percent and 20 percent HSCT airplanes in VFR conditions. Figures 5.3.2-3 and 5.3.2-4 show the same data for IFR conditions. All the Figures demonstrate that the proportion of arrival airplanes have the greatest impact on airplane throughput.

The change in peak throughput from approx. 60 percent arrivals in VFR conditions to approx. 30 percent arrivals in IFR conditions is a reflection of the increased spacing required between arrivals. Note that departure spacing requirements do not vary between VFR and IFR conditions. As a consequence, as spacing is increased for IFR conditions, it is possible to get more departures out for each arrival. The peak throughput is achieved with approx. two departures for each arrival.

5.3.3 WAKE TURBULENCE SPACING

Airplane spacing varies between VFR and IFR conditions, as noted in Table 5.2-1, with the VFR spacings being approximately 70 percent of the IFR spacings. In the parametric study of the effects of HSCT wake turbulence on following airplanes, the IFR spacings have been increased incrementally by 1.0 and 2.0 NM, and the VFR spacings have been increased by 0.7 and 1.4 NM. The results of the analysis are shown in Figures 7 through 10. The proportion of arrivals has been varied from 0.0 to 100.0 percent and the analysis was repeated for 10 percent and 20 percent of HSCT airplanes in the traffic mix.

In VFR conditions, when arrivals exceed 50 percent of the operations, throughput declines as airplane separation is increased, Figures 5.3.3-1 and 5.3.3-2. In IFR conditions, throughput is almost insensitive to airplane separation, see Figure 5.3.3-3 and 5.3.3-4. With 10 percent HSCT in the airplane mix, throughput starts to decline once arrivals exceed 67 percent of the operations. With 20 percent HSCT in the airplane mix, throughput declines once arrivals exceed 50 percent of the operations and the throughput penalty is greater.

In all cases, the greatest influence on throughput is that due to the proportion of arrivals in the operations.

5.3.4 COMMON APPROACH PATH LENGTH

The sensitivity of throughput to variations in the shared common path length was achieved by adding increments of 5 and 10 NM beyond the final approach path. The assumption was made that approach speed at turn-on would be 15 knots higher than the outer marker speed. Speeds were assumed to decline at a constant rate between turn-on and the outer marker, and again between the outer marker and the threshold. The quoted approach speeds are those at the outer marker. Other parameters varied in the analysis were;

proportion of arrivals in the airport operations,
proportion of HSCT airplanes in the traffic mix,
VFR and IFR conditions, and
approach speed.

The throughput plots are shown in Figures 5.3.4-1 through 5.3.4-4.

The throughput values during VFR conditions with arrivals only show the greatest variation with approach speed and distance, Figure 5.3.4-1 and 5.3.4-2. The throughput varies slightly with speed for a common approach distance of 5 NM but declines rapidly as this distance is exceeded, particularly between 5 and 10 NM and at high HSCT approach speeds.

Throughput, under IFR conditions with arrivals only, is relatively insensitive to HSCT approach speed up to 165 knots, Figure 5.3.4-1 and 5.3.4-2. Note that for common approach distances exceeding approximately 7 NM, throughput no longer is improved as approach speed is increased.

The throughput sensitivity with an operations mix of 50 percent arrivals and 50 percent departures is less sensitive to common approach path distance and HSCT approach speed changes than in the case of arrivals only. Figures 5.3.4-3 and 5.3.4-4. The greatest sensitivity is now in IFR conditions and the sensitivity is increased with approach speed and common approach distance change.

5.4 CONCLUSIONS

1. Adding additional airplanes of the HSCT or "heavy jet" type to the current SeaTac traffic mix is detrimental to the current airplane throughput which is penalized by approx. 5 percent for each 10 percent of additional large airplanes added.

2. Increasing HSCT approach speed above 145 Kts is additionally detrimental to throughput in VFR conditions with arrivals only. With a mix of arrivals and departures the spacing requirements to allow for departures is sufficient to mask the approach speed change.

3. Throughput is very sensitive to the mix of arrivals and departures in either VFR or IFR conditions.

4. Increasing wake vortex spacing for airplanes following HSCT airplanes is additionally detrimental to throughput. In VFR or IFR conditions, with arrivals only, throughput is reduced by 4 percent for each 10 percent of HSCT airplanes added. The reduction in throughput for mixed operations is less than 2 percent for each 10 percent of HSCT airplanes added.

5. Increasing the common approach path length for all airplanes without increasing the HSCT approach speed is not detrimental to throughput. However, increasing HSCT approach speed above 145 Kts in this situation is detrimental. With arrivals only, VFR conditions, an approach distance of 15 NM and 185 knots approach speed, throughput could be reduced by 7 percent for 10 percent of HSCT airplanes. In similar, but IFR conditions, throughput is reduced by approximately 5 percent.

6. Throughput is less sensitive to approach speed and common approach distance when mixed arrival and departure operations are conducted, versus the case of arrival operations only. The throughput penalty is in the range of 1 to 2 percent for each 10 percent of HSCT airplanes added.

7. A summary table of throughput penalties for the various operating conditions is given below. It should be re-emphasized that if the HSCT has an approach speed of the order of 145 Kts and a similar wake vortex system as a 747, then it will impact the throughput in no more serious a manner than a "heavy jet". But if it has approach speed of the order of 185 Kts or a significantly stronger wake vortex field (representative of the much higher cruise speed configurations) than there is a significant incremental impact solely due to these operational variables.

8. Further analysis of the potential HSCT impact on air traffic flow is required in the air corridors from SST cruise altitude down to the subsonic aircraft cruise altitude and then in descent down to the terminal area.

SUMMARY TABLE

THROUGHPUT CHANGE WITH 10% HSCT AIRPLANES

OPERATING CONDITION	CHANGE %	RELATIVE CHANGE %									
Addition of HSCT or "heavy jet", arrivals only, 145 knots, VFR	-4.2	Base				Base					
Addition of HSCT or "heavy jet", arrivals only, 145 knots, IFR	-2.5		Base				Base				
Addition of HSCT or "heavy jet", 50% arrivals, 145 knots, VFR	-4.9			Base							
Addition of HSCT or "heavy jet", 50% arrivals, 145 knots, IFR	-2.1				Base						
185 knots approach speed, arrivals only, VFR	-5.5	-1.3									
185 knots approach speed, arrivals only, IFR	-1.5		+1.0								
185 knots approach speed, 50% arrivals, VFR	-4.9			0							
185 knots approach speed, 50% arriavls, IFR	-0.3				+1.8						
+1.4 NM wake vortex separation, arrivals only, VFR	-4.2					-4.2					
+2.0 NM wake vortex separation, arrivals only, IFR	-3.8						-1.3				
15 NM common approach path, arrivals only, 145 knots, VFR	0.0							Base			
15 NM common approach path, arrivals only, 145 knots, IFR	-0.6								Base		
15 NM common approach path, arrivals only, 185 knots, VFR	-7.0							-7.0			
15 NM common approach path, arrivals only, 185 knots, IFR	-5.5								-4.9		
15 NM common approach path, 50% arrivals, 145 knots, VFR	0.0									Base	
15 NM common approach path, 50% arrivals, 145 knots, IFR	0.3										Base
15 NM common approach path, 50% arrivals, 185 knots, VFR	-1.2									-1.2	
15 NM common approach path, 50% arrivals, 185 knots, IFR	-4.2										-4.5

		VFR conditions				IFR conditions			
		Leading airplane class, VFR conditions				Leading airplane class, IFR conditions			
		1	2	3	4	1	2	3	4
Trailing Airplane Class	1	2.7	2.7	1.9	1.9	4.0	4.0	3.0	3.0
	2	2.7	2.7	1.9	1.9	4.0	4.0	3.0	3.0
	3	3.6	3.6	1.9	1.9	5.0	5.0	3.0	3.0
	4	3.6	3.6	1.9	1.9	5.0	5.0	3.0	3.0

Table 5.2-1. Arrival—Arrival Separation Distances, nmi

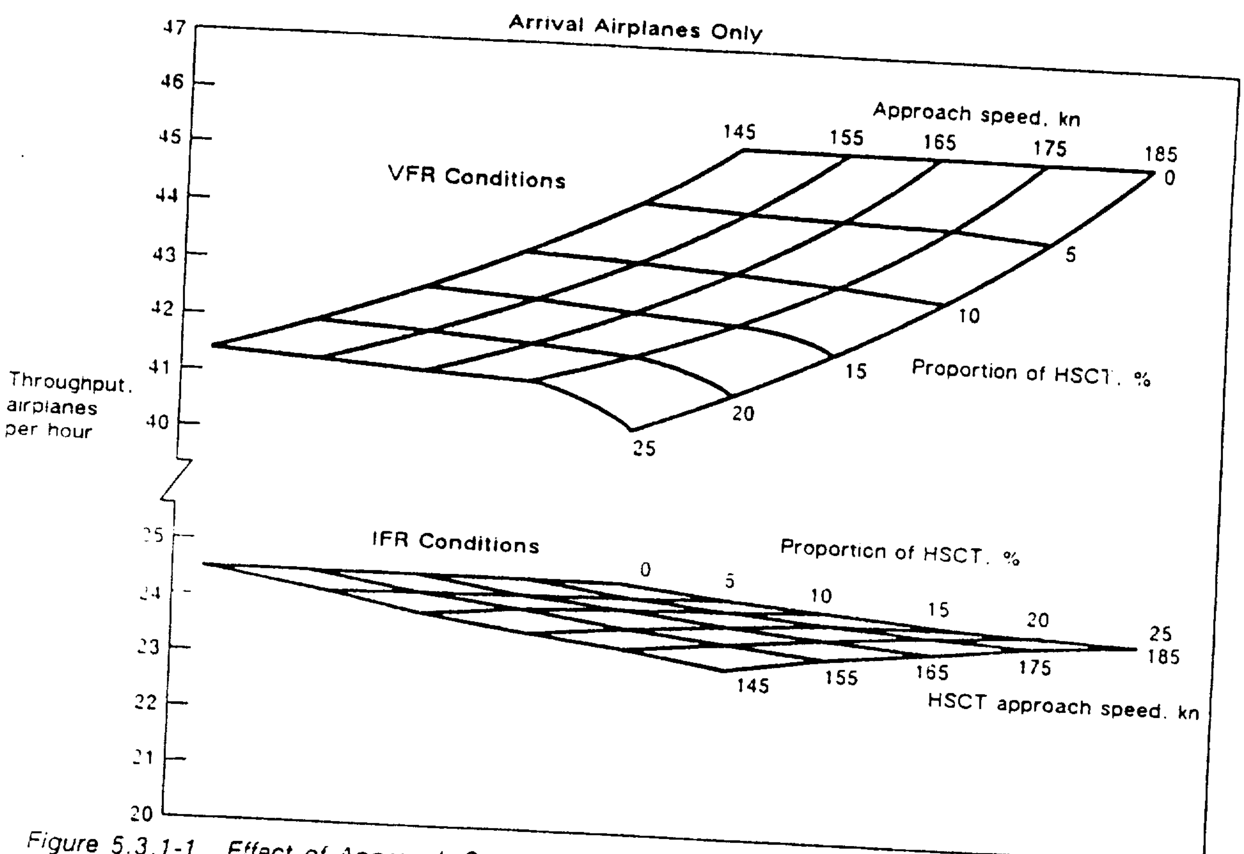


Figure 5.3.1-1. Effect of Approach Speed and Proportion of HSCT Airplanes in the Traffic Mix

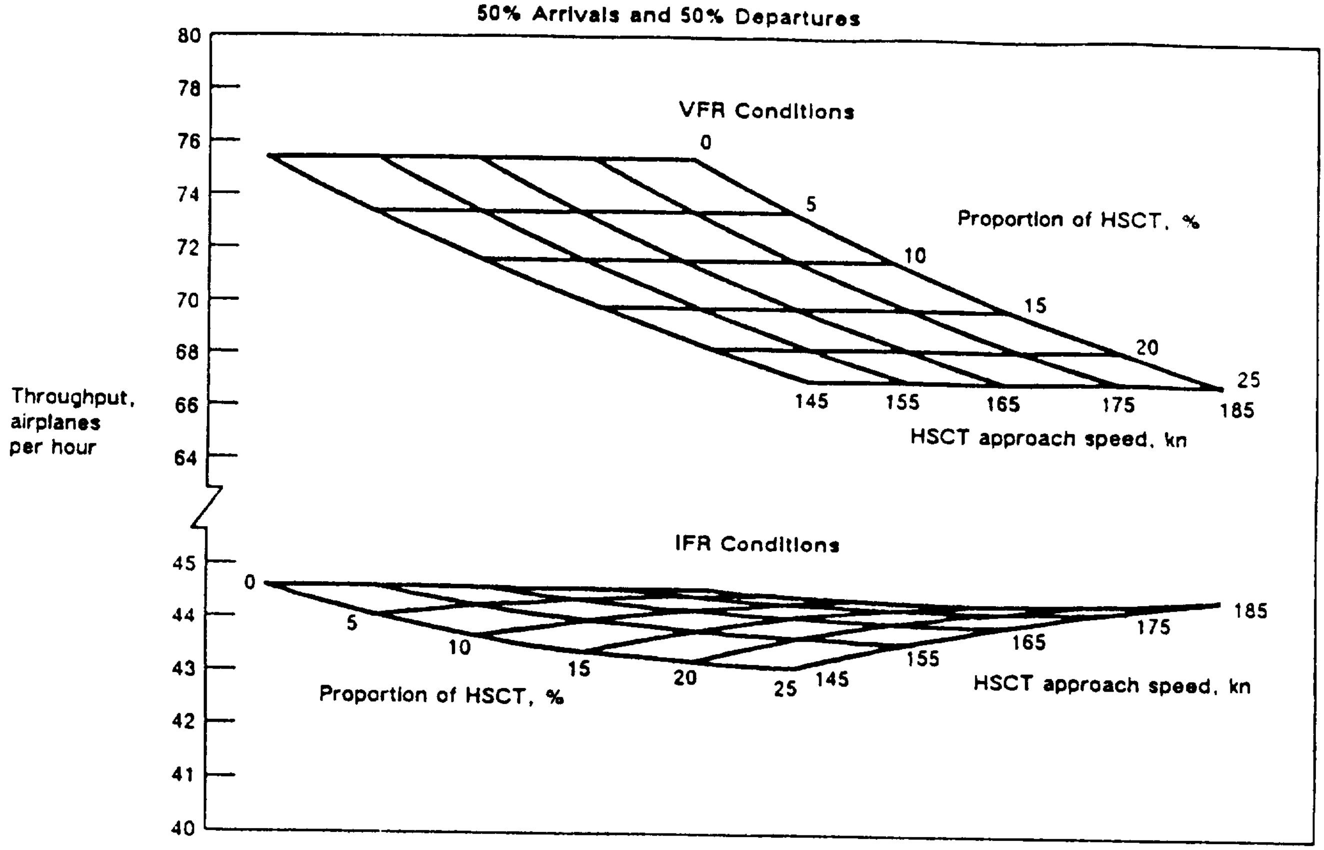


Figure 5.3.1-2. Effect of Approach Speed and Proportion of HSCT Airplanes in the Traffic Mix

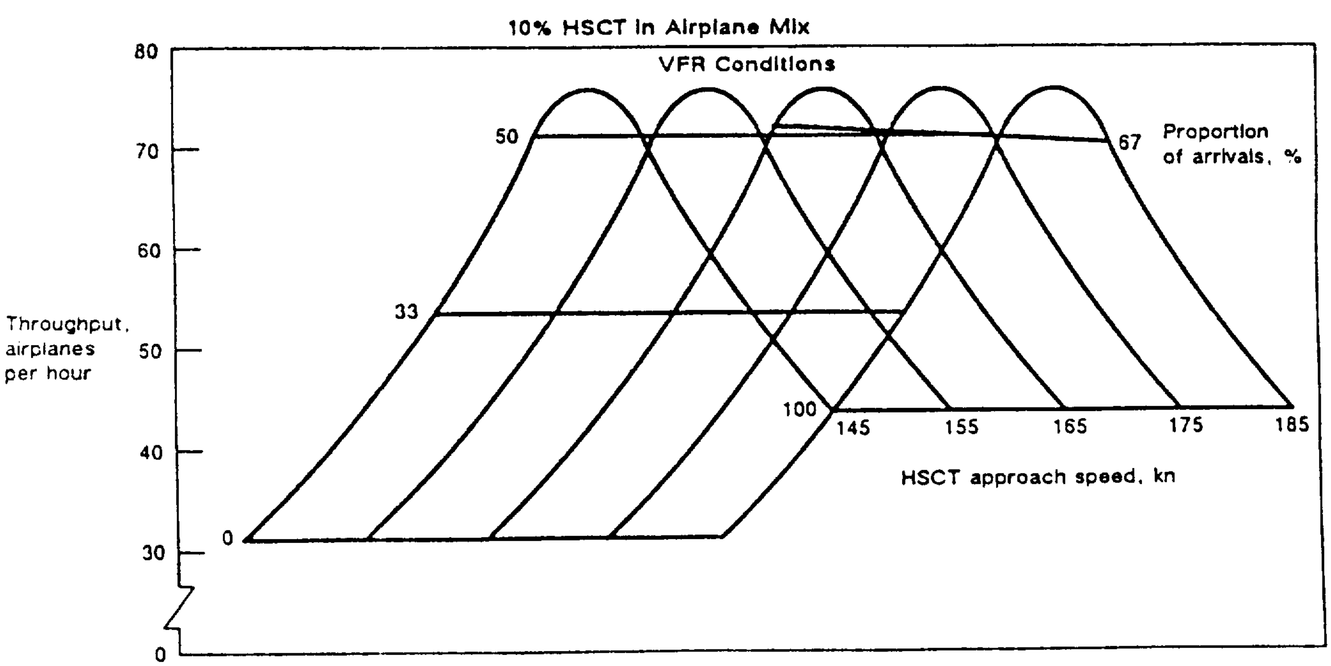


Figure 5.3.2-1. Effect of Approach Speed and Proportion of Arrivals in Airport Operations

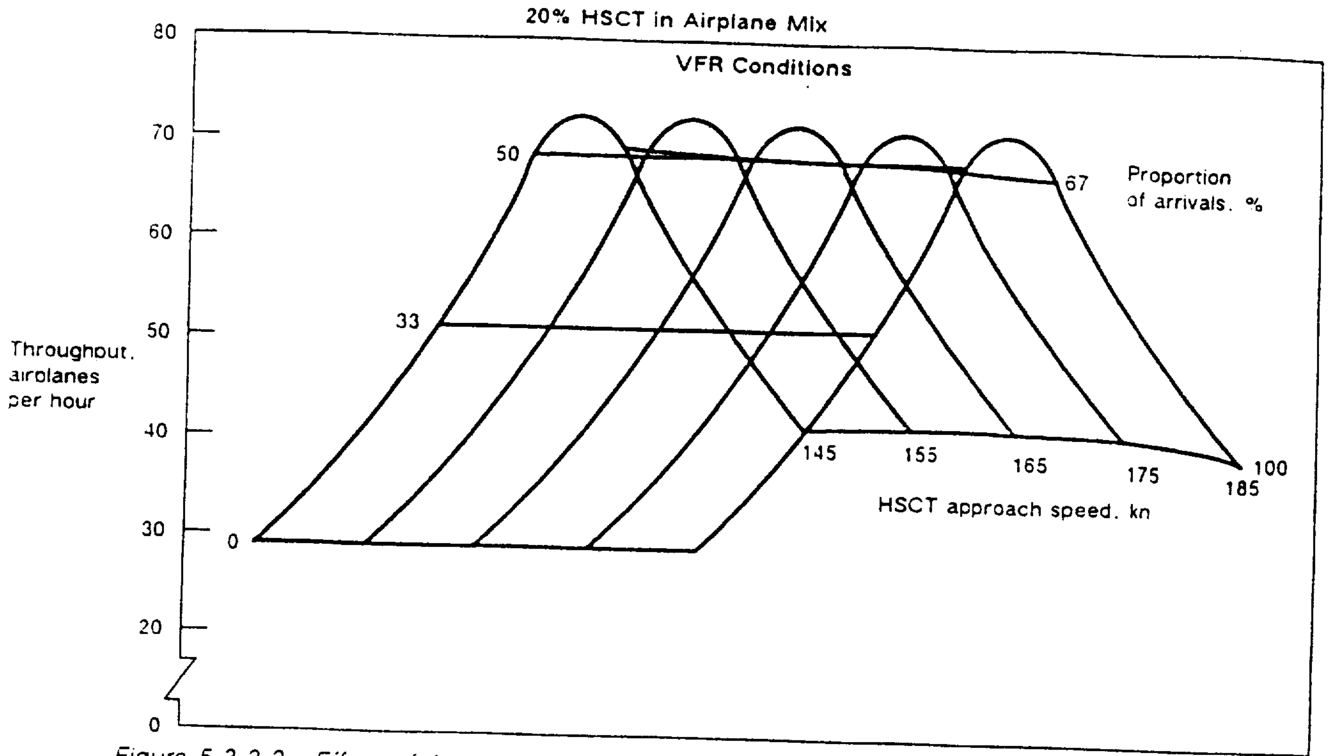


Figure 5.3.2-2. Effect of Approach Speed and Proportion of Arrivals in Airport Operations

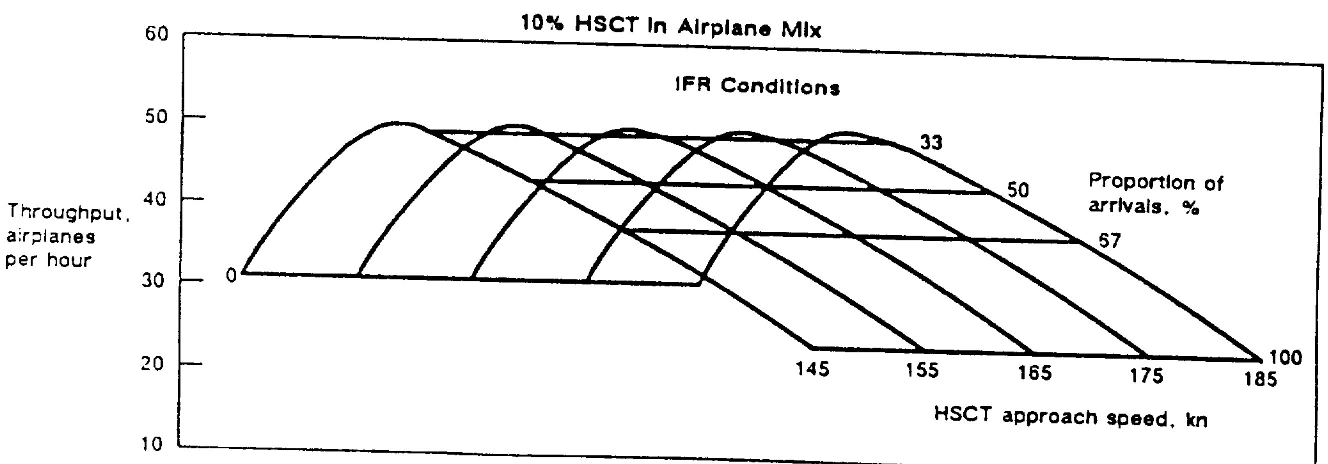


Figure 5.3.2-3. Effect of Approach Speed and Proportion of Arrivals in Airport Operations

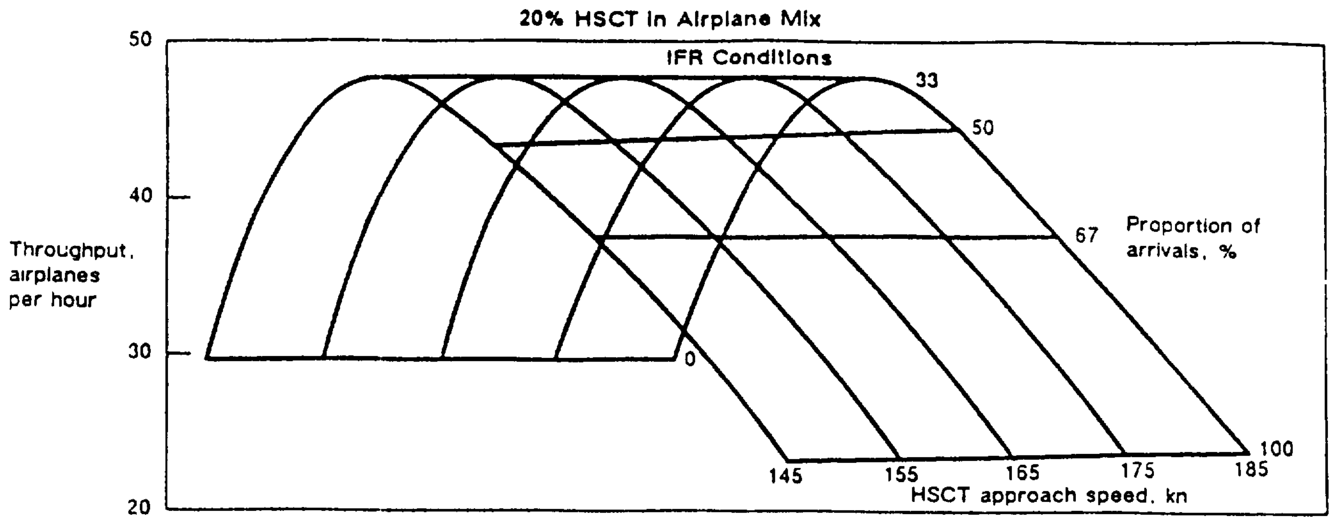


Figure 5.3.2-4. Effect of Approach Speed and Proportion of Arrivals in Airport Operations

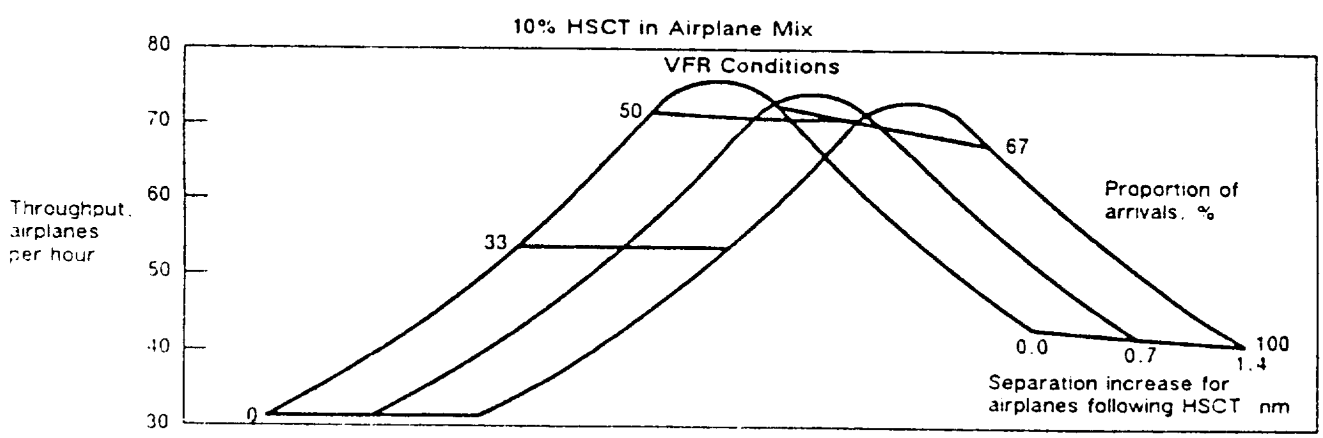


Figure 5.3.3-1. Effect of Wake Vortex Separation and Proportion of Arrivals in Airport Operations

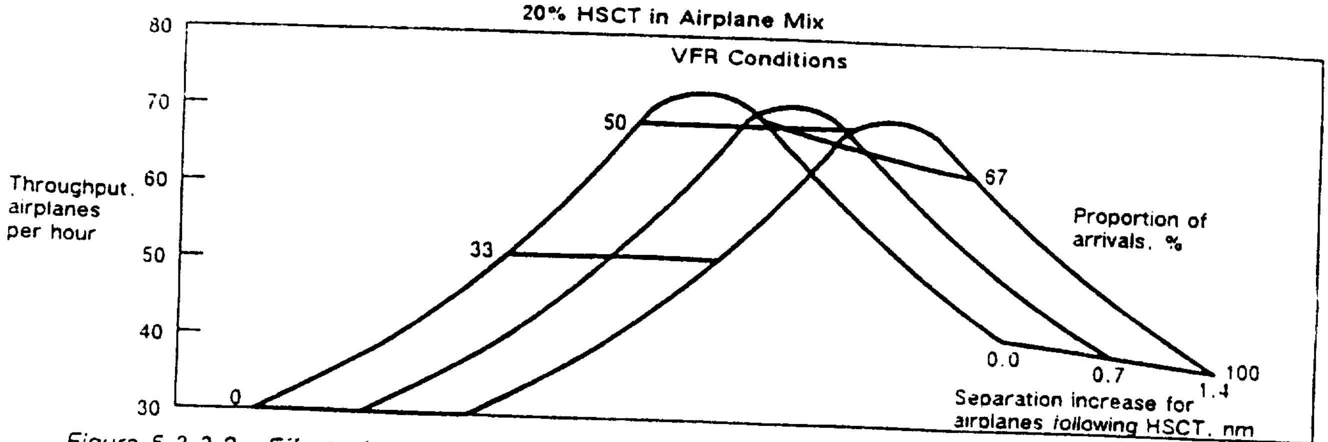


Figure 5.3.3-2. Effect of Wake Vortex Separation and Proportion of Arrivals in Airport Operations

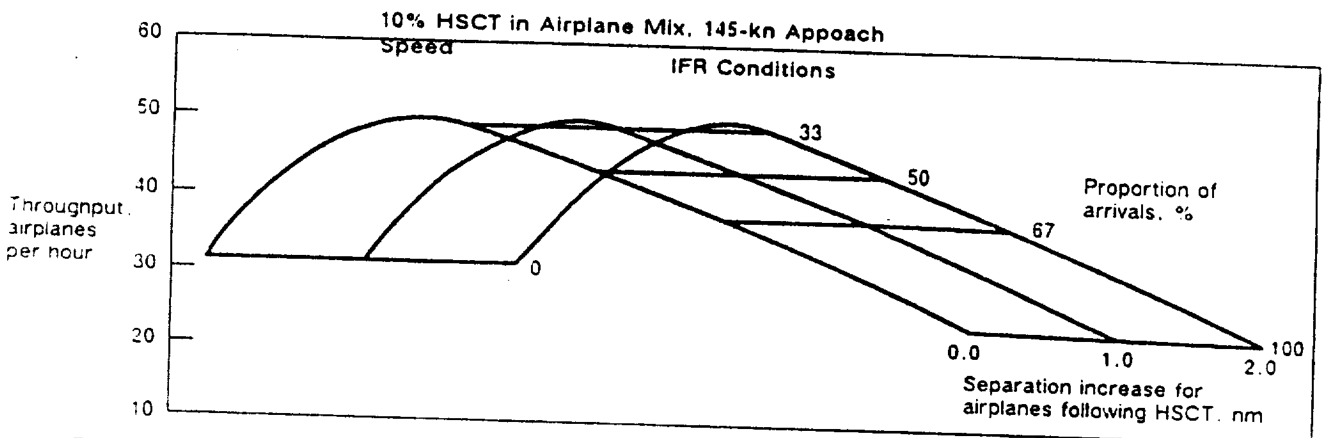


Figure 5.3.3-3. Effect of Wake Vortex Separation and Proportion of Arrivals in Airport Operations

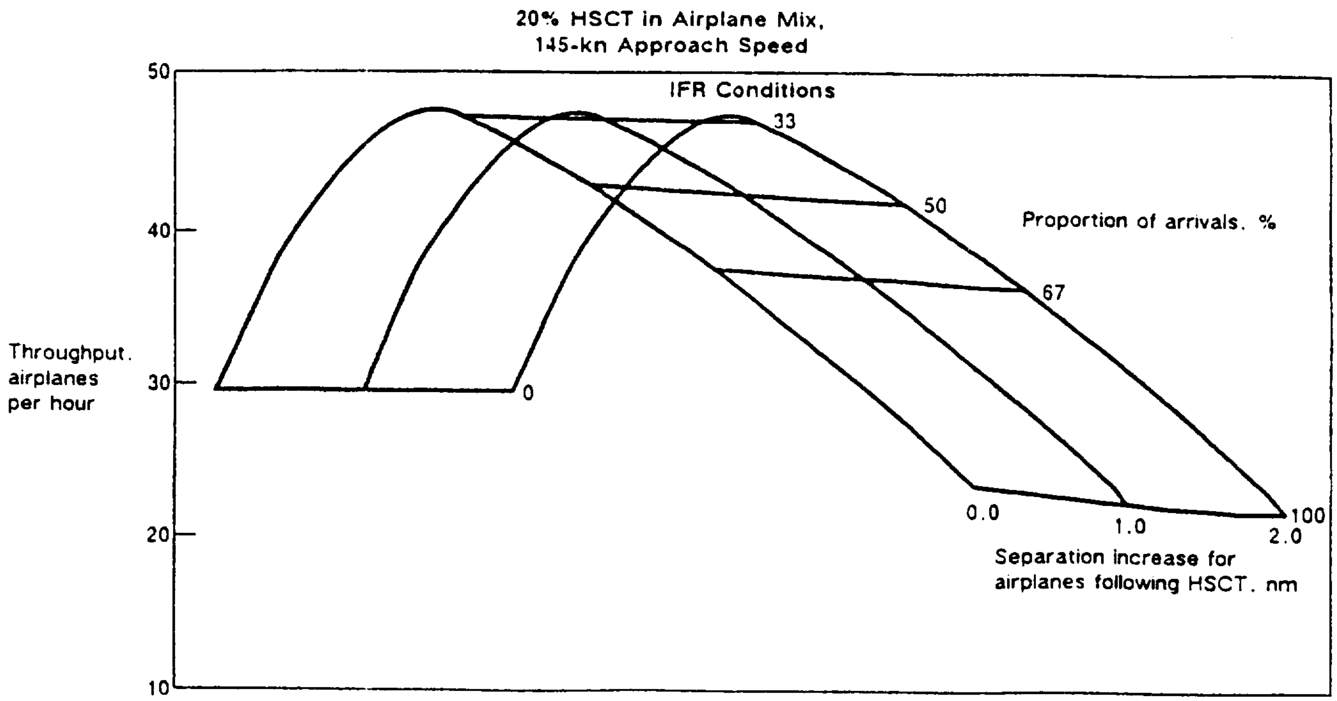


Figure 5.3.3-4. Effect of Wake Vortex Separation and Proportion of Arrivals in Airport Operations

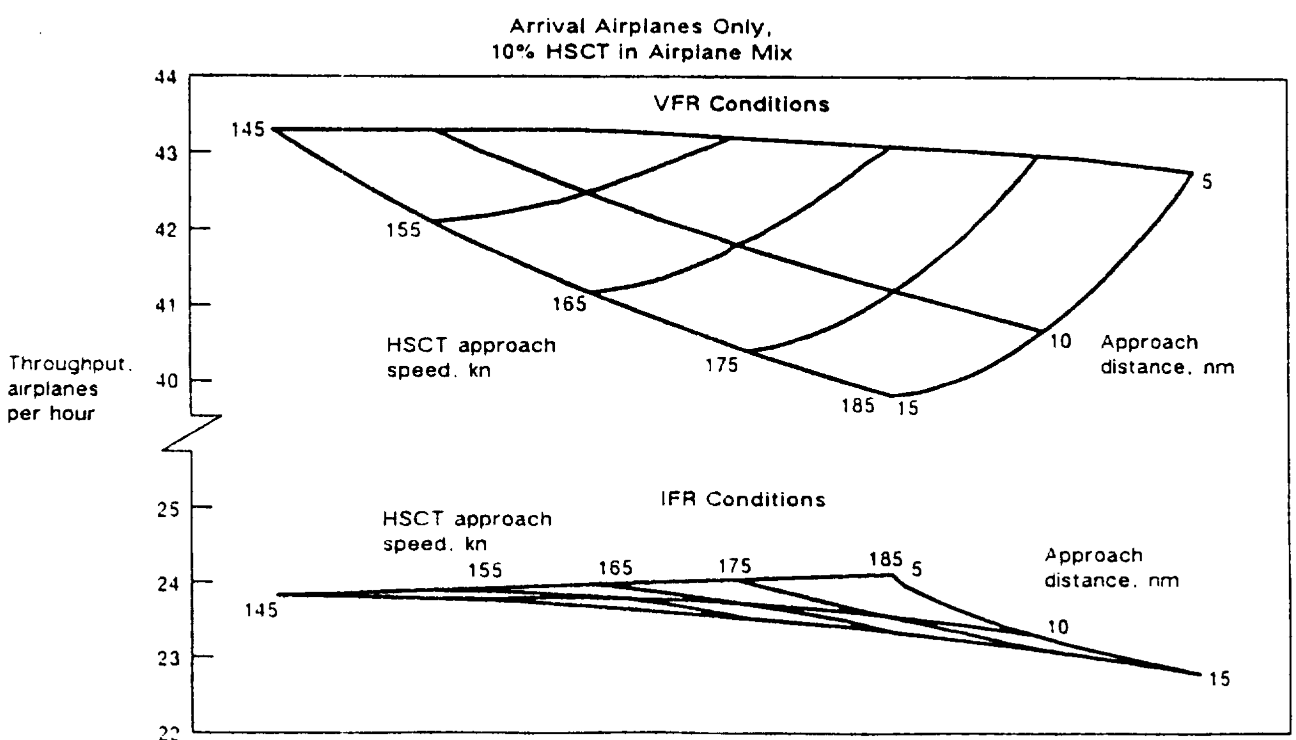


Figure 5.3.4-1. Effect of Approach Distance and Speed

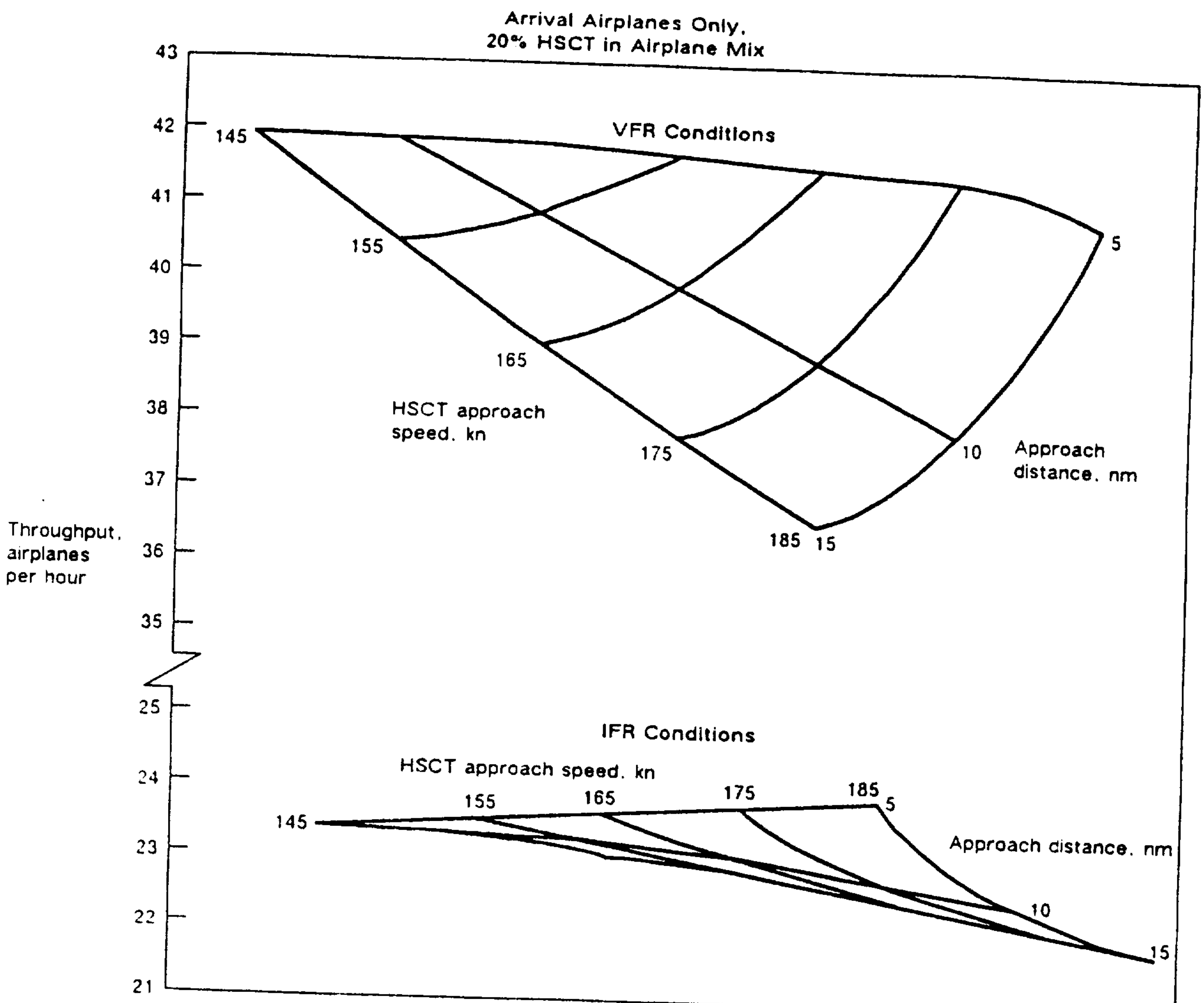


Figure 5.3.4-2. Effect of Approach Distance and Speed

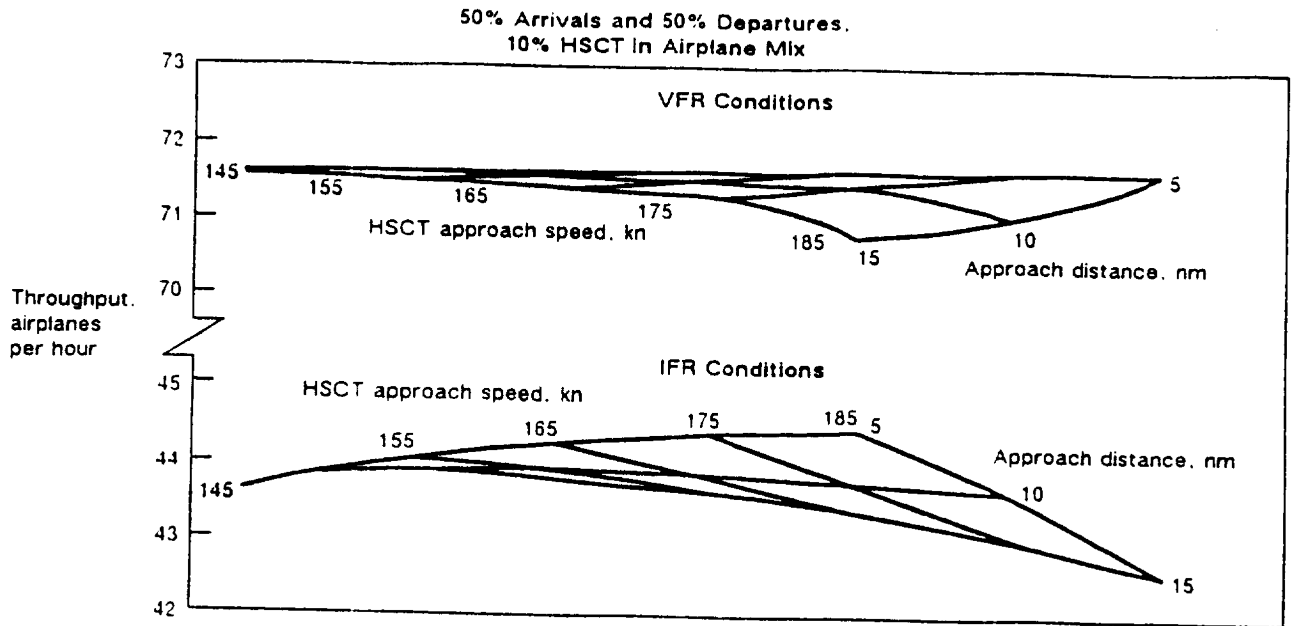


Figure 5.3.4-3. Effect of Approach Distance and Speed

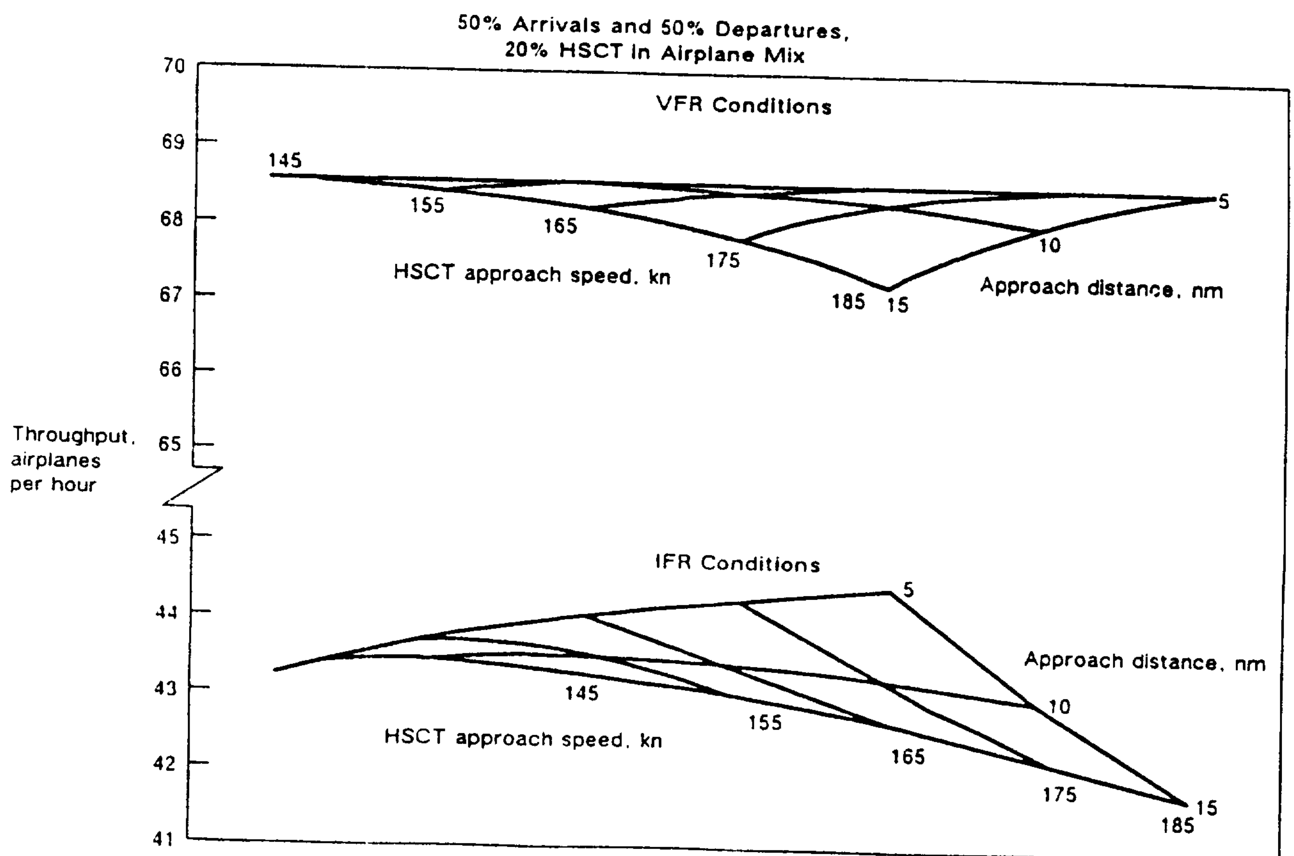


Figure 5.3.4-4. Effect of Approach Speed and Distance

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Final Report

16. Abstract

Studies relating to environmental factors associated with high-speed civil transports were conducted by the Boeing Commercial Airplane Group. The report includes: projected total engine emissions for year 2015 fleets of several subsonic/supersonic transport fleet scenarios; discussion of sonic boom reduction methods; discussion of community noise level requirements; fuels considerations; and air traffic control impact.

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